GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. D-48-678 (R538-0A0) GTRC/~~XXX~~ DATE 3 / 13 / 85

Project Director: Jon A. Sanford School/~~XXX~~ Architecture

Sponsor: The Research Foundation of State University of New York

Type Agreement: Research Agreement (Under Dept. of Ed. Prime 300-84-0247)

Award Period: From 10/1/84 To ~~9/30/85~~ ~~4-30-86~~ 10-31-86 (Performance) 9/30/85 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$ 111,957	$ 111,957
Funded:	$ 111,957	$ 111,957

Cost Sharing Amount: $ None Cost Sharing No: N/A

Title: Hand Anthropometrics

ADMINISTRATIVE DATA

OCA Contact Brian J. Lindberg X4820

1) Sponsor Technical Contact:

Dr. Edward Steinfeld
Office of Research Administration
516 Capen Hall
Suny of Buffalo
Buffalo, New York 14260

2) Sponsor Admin/Contractual Matters:

Peter N. Tenbeau, Deputy Director
Contract and Grant Administration
The Research Foundation of Suny
P. O. Box 9
Albany, New York 12201
(518) 434-7103

Defense Priority Rating: n/a Military Security Classification: n/a
(or) Company/Industrial Proprietary: n/a

RESTRICTIONS

See Attached n/a Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with None proposed or anticipated

COMMENTS:

MAR 1985
RECEIVED
Research Reports
Office

COPIES TO: SPONSOR'S I. D. NO. 02.400.000.85R01

Project Director	Procurement/EES Supply Services	GTRC
Research Administrative Network	Research Security Services	Library
Research Property Management	Reports Coordinator (OCA)	Project File
Accounting	Research Communications (2)	Other Jones

FORM OCA 65 285

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 3-13-87

Project No. D-48-678 School/~~Lab~~ Arch.

Includes Subproject No.(s) N/A

Project Director(s) Jon A. Sanford GTRC / ~~GIT~~

Sponsor The Research Foundation of State University of New York

Title Hand Anthropometrics

Effective Completion Date: 10-31-86 (Performance) 10-31-86 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [x] Closing Documents
- [x] Final Report of Inventions - Questionnaire sent to P.I.
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ______

Continues Project No. ______ Continued by Project No. ______

COPIES TO:

Project Director
Research Administrative Network
Research Property Management
Accounting
Procurement/GTRI Supply Services
Research Security Services
Reports Coordinator (OCA)
Legal Services

Library
GTRC
Research Communications (2)
Project File
Other Ina Lashley
Angela DuBose
Russ Embry

FORM OCA 69.285

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
ATLANTA, GEORGIA 30332

COLLEGE OF ARCHITECTURE
RESEARCH PROGRAM
(404) 894-3476

148-678

MEMORANDUM

TO : Ed Steinfeld

FROM: Jon Sanford and Jim Bostrom

DATE: February 27, 1985

PROGRESS REPORT

Hand Anthropometrics Project

February 1985

We are currently developing the survey methodology including specific responses to:

1. Description of methods planned for building survey, i.e., what buildings will be surveyed and criteria for selection;

2. Characteristics of different products based on preliminary investigations to help in development of the matrices;

3. Description of the detailed Focus Group Methodology;

4. Schedule for first three months of work.

This information will be forwarded to the Buffalo research team by March 15, 1985.

The two Atlanta Focus group meetings have been scheduled for March 8 and March 18th at Georgia Tech. The first group will be a meeting of rehabilitation specialists, researchers, and the project team (see attached Focus group handout). The second group will be a meeting of consumers with hand/arm disability. At this time the following consumers are expected to attend:

		Type of Disability
1.	Richard Mouzon	Quadriplegic
2.	Marlene Rosshirt	Head injury, one sided spastic
3.	Michael Weeks	Paraplegic, hand involvement
4.	Dave Webb	Quadriplegic
5.	Ward Buzzell	Cerebral Palsy
6.	Ricky Handley	Head injury, hemiplegic

Participants with other disabilities are being recruited.

During the next week we will develop the procedures for the Focus Group meetings.

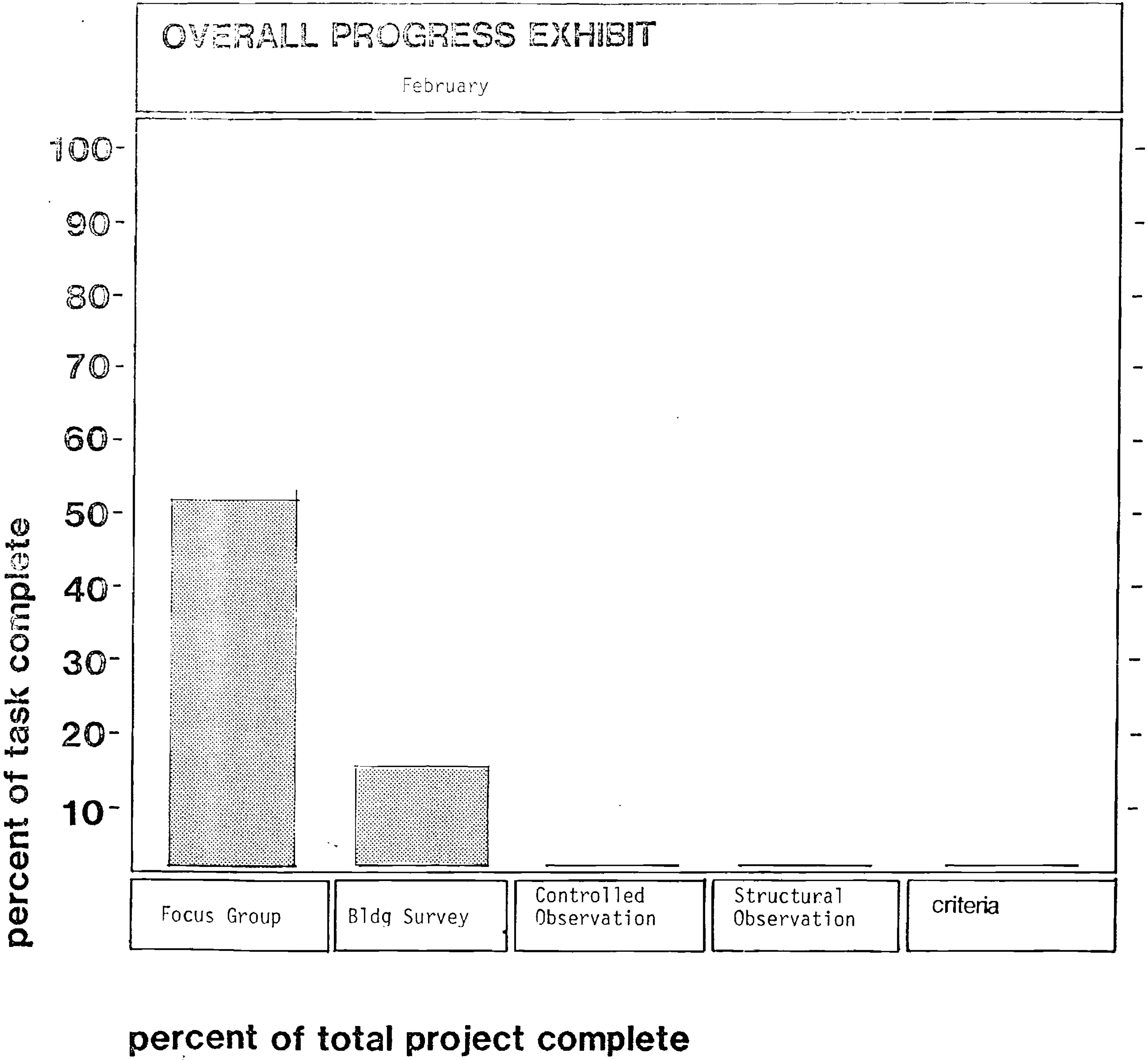

OVERALL PROGRESS EXHIBIT
February
100
90
80
70
60
50
40
30
20
10
percent of task complete
Focus Group
Bldg Survey
Controlled Observation
Structural Observation
criteria
percent of total project complete

Exhibit Of Expenditures

Tasks	Sanford	Bostrom	Secretary	Fringe @ 23.4%	Research Ass'ts	Consultants	Material Supplies	Equipment	Travel	Overhead @ 55.3%	Total
Focus Group	2138	579	0	636	3916	0	0	0	0	3743	10512
Building Survey		579		135						395	1109
Controlled Observation											
Structual Observation											
Criteria for Use											
Total											11620

Manpower Report

(Person Days) February

Tasks / Personnel	Sanford	Bostrom			Secretary	Research Ass'ts			
Focus Group	5.4	2.7			0	14.4			
Building Survey		2.7							
Controlled Observation									
Structual Observation									
Criteria for Use									
Total	5.4	5.4			0	14.4			
Cost	511	579			0	1291			

Manpower Report

Projected for March

(Person Days)

Tasks / Personnel	Sanford	Bostrom			Secretary	Research Ass'ts			
Focus Group	2.7	2.7			5.4	7.2			
Building Survey	2.7	2.7			5.4	7.2			
Controlled Observation									
Structual Observation									
Criteria for Use									
Total	5.4	5.4			10.8	14.4			
Cost	511	579			640	1291			

Hand Anthropometrics

Overview

It is estimated that about three million people over the age of 18 have difficulties with handling and fingering (Nagi, 1975). This estimate includes many people with permanent disabilities and chronic conditions including: arthritis, amputation, burns, muscular dystrophy, cerebral palsy, multiple sclerosis, Parkinson's Disease, quadriplegia, paraplegia and neurological disorders. Many of these conditions exist as multiple disabilities which means that a large proportion of the people with handling and fingering problems have other disabilities as well. Thus, they are among those who can benefit most highly from barrier-free design.

Because of the large number of individuals with hand impairments, hand anthropometrics have long been recognized as an important concern in the accessibility and useability of the built environment. As far back as 1961, the original ANSI A117.1 Standard included design criteria to improve accessibility of buildings for people who had difficulty using their hands and fingers. Many other codes and standards include such recommendations as well. However, due to the lack of research-based design data, all of the existing codes have addressed this issue in either a very general sense or through prescriptive requirements that exclude a wide array of design solutions. For example, the ANSI Standard A117.1 (1980) states that "controls and operating mechanisms shall be operable with one hand and shall not require tight grasping, pinching or twisting of the wrist." Some codes have mandated lever handles to the exclusion of push-plates or other devices that may also be satisfactory. This project will generate a database and use it to propose design guidelines and requirements for devices and mechanisms intended to be used by hand.

Czaja (1983), in her review of hand anthropometrics, demonstrates how this subject has been neglected in barrier-free design research. She cites only six studies that provide hard data: Nichols (1966), Johnson (1981), Woods (1980), Czaja and Steinfeld (1980), Lauback et. al. (1981), British Leyland (1974). While there have been other studies concerning hand anthropometrics of disabled and elderly people, the aforementioned are the only ones that contain data for design. The data provided in these few studies, however, either focus on isolated and limited concerns, have used very small samples of subjects or are incomplete on many issues.

Czaja (1983) identified two major knowledge gaps regarding design for people who have difficulty using their hands and fingers:

1. measurements of hand anthropometrics and biomechanics, and

2. comparison of the useability of various types of hand controls.

These knowledge gaps extend beyond the use of buildings to all types of appliances and devices that may be used by both able-bodied and disabled people. As a result, hand anthropometric and biomechanical data can have a major impact on building use and convenience in all facets of everyday life, especially employment, education and housing. Our constant interaction with the physical environment includes a continuous emphasis on actuating and deactuating devices (e.g. light switches), pushing and pulling objects (e.g. doors and cabinets), setting controls (e.g. stove knobs), using the environment to support our bodies (e.g., railings, grab bars), using tools in which we extend our body capabilities and using receptacles and depositories.

OBJECTIVES

The objectives of this project are to:

1. Develop and implement a research methodology to gather human performance data on people who have limited or no use of their arms, hands and/or fingers. The methodology will focus on static and functional anthropometric measurement of hands and related parts of the body and the biomechanics of hand activity;

2. Collect and record data in both the laboratory and in the field in the most cost effective manner to insure a valid, extensive database that is generalizable to broader populations of disabled people with hand impairments;

3. Compare the useability of various types of devices and mechanisms intended to be used by hand; and

4. Develop recommendations for performance, design, and installation criteria for such equipment, devices and mechanisms;

Although it is clear that hand anthropometrics and biomechanics should be a major topic of barrier-free research, there are four difficult problems in implementing research on these topics:

1. As indicated above, there are many disabling conditions that affect the use of hands and fingers. These conditions are manifest in a variety of ways and the abilities of people with physical disabilities vary considerably. Assembling a representative subject sample involves a great deal of time and effort in order to insure that as many physical problems as possible are represented. It also requires measuring the basic functional ability of each subject to insure that the findings derived from the research can be generalized to all groups of disabled people. A subject sample cannot be limited to only those people who have one chronic condition (e.g., arthritis) or who reside in a residential institution. Such samples may be highly biased and unrepresentative of the entire population of people with handling and fingering problems. Therefore, individuals with multiple disabilities must be included in the subject sample.

2. Because of the range of potential devices and controls a large variety of objects must be tested. Those devices mentioned previously are only a sample of the devices which could be used, and comparing the useability of all devices and mechanisms that are used by hand may well prove to be impossible. Not only is there a range of designs for each type of control/device (for example, there are at least four different basic door opener types: knob, lever, push plate, pull

hook), but hand anthropometrics and biomechanics also involve a large number of variables such as vertical location, horizontal location, type of control, size, texture, complexity, logic, feedback, activation method, force required, mode of activation and visibility (Faste, 1976).

3. While the performance of a control or mechanism is based on the ability or inability of an individual to use it, issues of safety, convenience and comfort are a function of the type of equipment on which the mechanism is found. As a result a range of types of equipment to be studied must also be established.

4. Effective design criteria which are applicable to a range of settings and that can be used in enforceable standards must be developed. However, the context in which a device or mechanism is used or a piece of equipment is located may have a great impact on its actual useability and accessibility. Further, the range of contexts cannot be adequately simulated in laboratory testing. As a result, the research which must identify the appropriate settings in which to conduct the field research.

When the range of different disabilities and possible functional abilities is considered in the context of the environmental variables, the highly complex nature of the problem becomes evident. The purpose of the focus group is, therefore, to consider the four problem areas listed above in order to focus the research on the most crucial and representative:

1. Hand impairments
2. Devices, controls and mechanisms
3. Equipment and tools
4. Settings and buildings

Focus Groups

The focus group discussions will provide an opportunity for both disabled consumers and experts to describe their experiences in the operation of various controls and devices and to alert the researchers to specific problems, dysfunctions or hazards. Each workshop will bring together 10 to 12 people including two members of the research team. Those asked to participate will include disabled consumers, rehabilitation professionals (such as occupational therapists and physical therapists), medical researchers, human factors specialists and physicians.

The product of these groups will be to focus the research on:

1. Problems encountered by persons with hand and arm disabilities;

2. The types of controls, devices and mechanisms which cause the most problems for individuals with hand impairments;

3. The types of equipment (e.g., vending machine) which cause problems; and

4. The types of places (setting and building types) which are most important in which to conduct the study.

The following lists of settings, equipment and devices have been compiled by the research team. These lists are not necessarily complete nor are the items on the lists necessarily conclusive. Rather, they represent potential items which might be studied and are intended to provide focus group participants with a starting point for discussion. The primary criteria for the selection of specific devices, equipment and settings for study should be either their wide use or their high potential for use by disabled persons.

... Devices Which Might Impact Persons With Hand Impairments

	Setting Type	Type of Equipment	Types of Devices*
PUBLIC USE	A. Public Buildings 1. Civic Center 2. Community Center 3. Library 4. Post Office 5. Hospital 6. School 7. Stadium/Arena 8. Courthouse 9. Museum/Zoo 10. Municipal Buildings 11. Transportation Facilities (Airport, Train Subway, Bus) 12. Park/Play Area 13. Parking Lot 14. College Campus B. Buildings Open to Public 1. Bank 2. Place of Worship 3. Cafeteria/Restaurant 4. Hotel/Motel 5. Grocery Store/Supermarket 6. Shopping Center 7. Gym/Spa 8. Laundromat 9. Office Building 10. Retail Stores 11. Theater	1. Mailslot/mail box 2. Post Office Box 3. Public telephone/booth 4. Toilet 5. Lavatory/faucet 6. Soap and towel dispenser 7. Fire Alarm 8. Fire extinguisher 9. Vending/stamp/newspaper machines 10. Fare gate (as in a transit station) 11. Turnstile 12. Copying machine 13. Trash can cover 14. Elevator buttons 15. Automatic Teller 16. Handrail/grab bar 17. Locker 18. Self-service condiment/beverage dispensers 19. Parking meter 20. Pedestrian cross walk button 21. Automatic parking gate. 22. After hours depository 23. Pass trays (e.g. at drive-up windows 24. Change return 25. Drive up banking (vacuum tube)	I. Controls 1. Actuating (on-off) a. toggle b. knob c. button d. touch 2. Setting a. knob b. selector c. touch II. Pulls/Handles III. Receptacles 1. Inserting a. ticket slots b. trash can cover c. coin slots d. mail slots 2. Removal a. pass trays b. coin returns c. ticket machines IV. Support Devices 1. Grab bars 2. Handrails V. Tools / Machinery 1. Cranks 2. Levers 3. Wheels
PERSONAL USE	A. Residence/Institutional Living 1. Single Family House/Condominium 2. Apartment 3. Elderly Housing 4. Public Housing 5. Nursing Homes 6. Other Institutional Settings 7. Dormitory B. Workplace 1. Office 2. Factory 3. Store C. Automobile	1. Light Switch 2. Doorbell 3. Door/door knob 4. Window 5. Thermostat 6. Cabinet doors/handles 7. Cabinet drawers 8. Sink/Lavatory 9. Oven/stove 10. Refrigerator 11. Toilet 12. Lavatory faucet 13. Tub/shower 14. Telephone 15. Typewriter/computer 16. Safe deposit box 17. Safe 18. File cabinet	*public and personal

List of Participants: Focus Group 1

Participants in the first focus group represent a wide range of areas of expertise from hand anthropometry to research. The purpose of assembling this multidisciplinary group is to try to address the breadth of issues which impacts hand anthropometrics and to do so in a way which is not only testable, but will produce valid, applicable and useful information.

1. Dr. John Basmajian
   Georgia Institute of Technology

2. Mr. Michael Brown, O.T.R.
   Hand Rehabilitation Clinic of Atlanta

3. Mr. David Clark, O.T.R.
   Director, Grady Hospital O.T. Clinic

4. Ms. Chris Doane, O.T.R.
   Occupational Therapy Dept.,
   St. Joseph's Hospital

5. Dr. Frank Joseph
   Surgery of the Hand
   Northwest Medical Center

6. Ms. Jessie Gladden
   Georgia Physical Therapy

7. Ms. Beth Sampson, O.T.R.
   Shepherd Spinal Clinic

8. Dr. Steven Wolf, Ph.D.
   Physical Therapy Dept.
   Emory University Hospital Center
   for Rehabilitation Medicine

BIBLIOGRAPHY

American National Specifications for Making Buildings and Facilities Accessible to,and Usable by, Physically Handicapped People, American National Standards Institute, Inc., New York, A117.1,1980.

British Leyland Ltd. "An Investigation of Factors Affecting the Use of Buses by both Elderly and Ambulant Disabled Persons",for the Transportation and Road Research Laboraatory,1974.

Czaja,S. and E. Steinfeld. *Human Factors Research with Disabled Children*, People's Center for Housing Change, Buffalo, N.Y., 1980.

Czaja,S. *Hand Anthropometrics*. Technical paper for the U.S. Architectural and Transportation Barriers Compliance Board, 1983.

Johnson,B. "Door-use Study", National Research Council, Canada, Division of Building Research, 1981.

Lauback,L., R. Glaser and AQ. Suryaprasad. "Anthropometry of Aged Male Wheelchair-dependent patients," *Annals of Human Biology*, V.8, N.1, 1981, pp.25-29.

Nichols,J. "Door Handles for the Disabled: An Assessment of Their Suitability", *Annals of Physical Medicine*, V.8, N.5, Feb. 1966, pp.180-183.

Woods,W. *Disability and Building Codes: A Quantitative Study*, Southwest Arathritis Center, University of Arizona, Tucson, Az, 1980.

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
ATLANTA, GEORGIA 30332

COLLEGE OF ARCHITECTURE
RESEARCH PROGRAM
(404) 894-3476

M E M O R A N D U M

TO : Ed Steinfeld

FROM: Jon Sanford and Jim Bostrom

DATE: March 25, 1985

PROGRESS REPORT

Hand Anthropometrics Project

March 1985

1. Focus Group #2. A second Focus Group will be held at Georgia Tech on April 8, 1985. We expect 7-10 consumers with hand disabilities to attend this meeting.

2. Building Survey Methodology. We are very close to completing a draft of the methods and procedures that will be used for the building surveys. The draft should be ready for review by the time Jon Sanford comes to Buffalo for the April 11 Focus Group Session.

3. Project Schedule. A project schedule has been developed that outlines the work from January through May. A copy of the schedule is enclosed with this report.

During April we will complete the report of the Focus group meetings, pre-test the building survey, begin conducting the surveys, and begin the survey analysis.

Hand Anthropometrics Project

Research Schedule - Georgia Tech

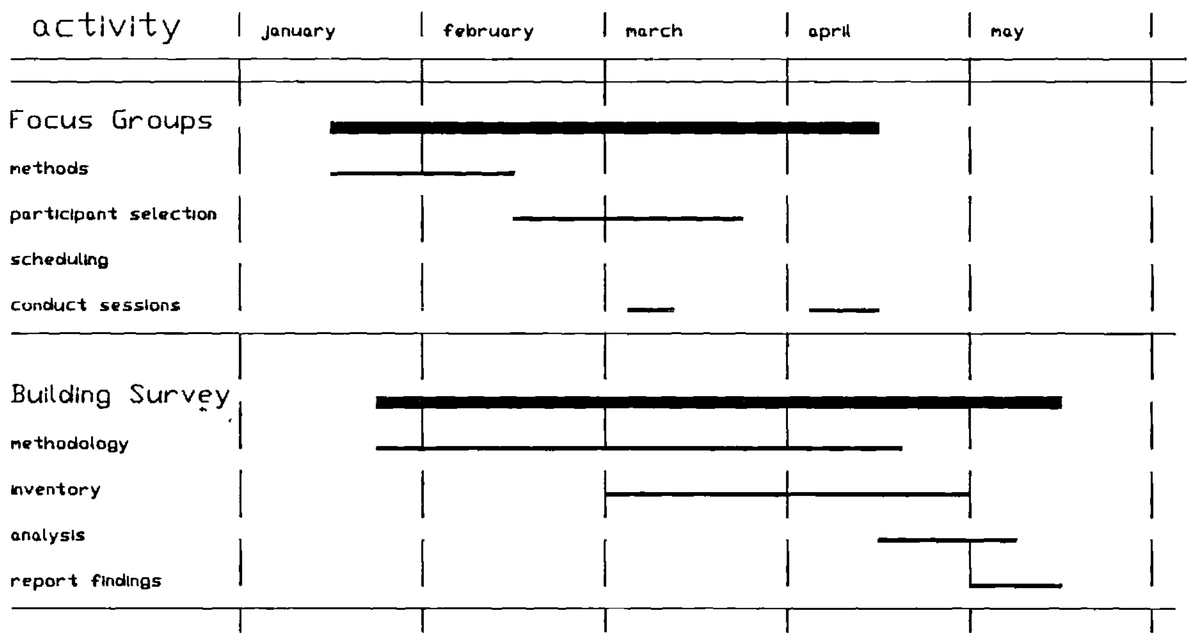


Exhibit Of Expenditures

Tasks	Sanford	Bostrom		Secretary	Fringe @ 23.4%		Research Ass'ts	Consultants		Material Supplies	Equipment	Travel		Overhead @ 55.3%					Total
Focus Group	2344	869		320	826		4561	0		30	0	0		4950					13900
Building Survey	205	868			251		646			170				395					2535
Controlled Observation																			
Structual Observation																			
Criteria for Use																			
Total																			16435

Figure 12 Monthly Progress Report

Manpower Report
(Person Days)

MARCH

Tasks / Personnel	Sanford	Bostrom			Secretary	Research Assts.					
Focus Group	2.7	2.7			2.7	7.2					
Building Survey	2.7	2.7			2.7	7.2					
Controlled Observation											
Structural Observation											
Criteria for Use											
Total	5.4	5.4			5.4	14.4					
Cost	511	579			320	1291					

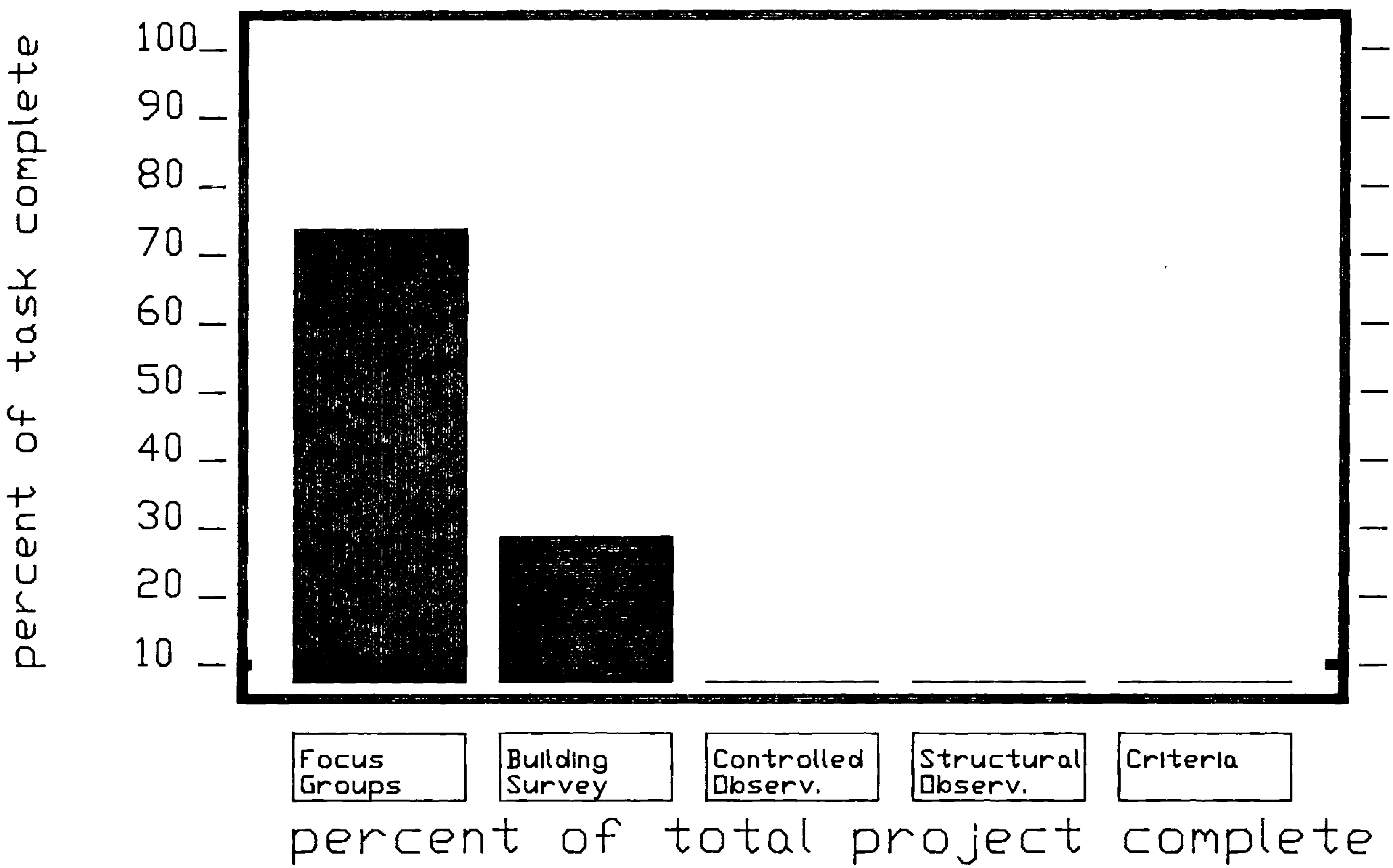
Manpower Report
(Person Days)

PROJECTED FOR APRIL

Tasks / Personnel	Sanford	Bostrom			Secretary	Research Assts.					
Focus Group	2.7	2.7			5.4	3.0					
Building Survey	2.7	2.7			5.4	11.4					
Controlled Observation											
Structural Observation											
Criteria for Use											
Total	5.4	5.4			10.8	14.4					
Cost	511	579			640	1291					

OVERALL PROGRESS EXHIBIT

February 1985



D48-678

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
ATLANTA, GEORGIA 30332

COLLEGE OF ARCHITECTURE
RESEARCH PROGRAM
(404) 894-3476

MEMORANDUM

TO : Ed Steinfeld

FROM: Jon Sanford and Jim Bostrom

DATE: April 30, 1985

PROGRESS REPORT

Hand Anthropometrics Project

April 1985

1. Focus Group #2. A second Focus Group meeting was held at Georgia Tech on Monday April 8, from 7- 10:00 p.m. The results of the meeting and a list of participants is included in the Focus Group Meeting Report.

2. Focus Group #3. Jon Sanford flew to Buffalo on April 4 to participate in the third Focus Group meeting. Findings of this meeting are incorporated in the Focus Group Meeting Report.

3. Building Survey Methodology. A building survey methodology has been developed and is currently being pretested. Attached is the three sheet form used for Data recording during the survey. Following the pretest a complete description of the building evaluation will be sent to Buffalo.

During May we will finalize the building survey methodology, begin conducting the building survey and start analyzing the building survey data. We expect to forward the survey methodology to you by May 8, 1985.

Manpower Report
(Person Days)

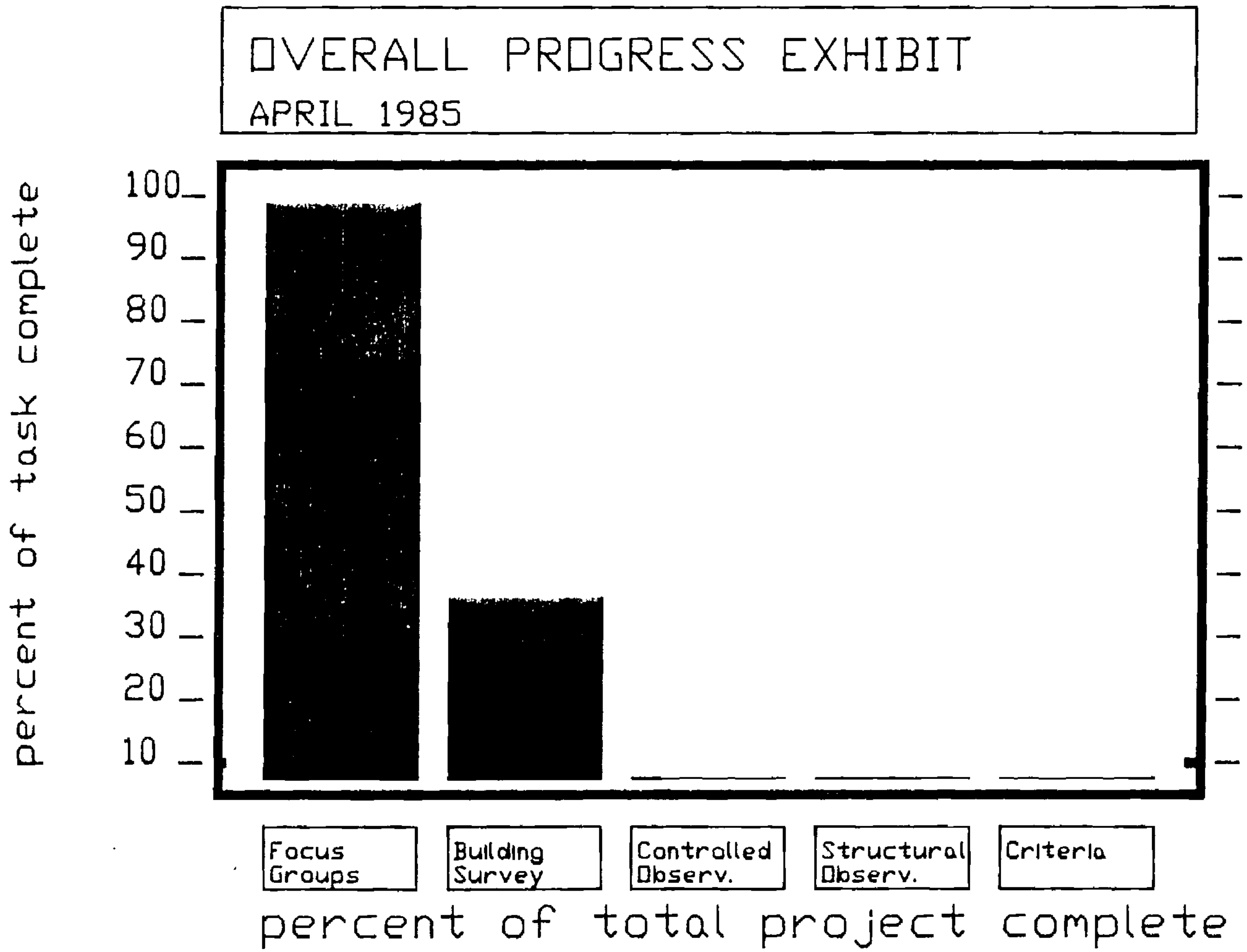
APRIL

Tasks / Personnel	Sanford	Bostrom			Secretary	Research Assts.					
Focus Group	1.5	1			3.0	8.5					
Building Survey	3.9	4.4			2.4	13.1					
Controlled Observation											
Structural Observation											
Criteria for Use											
Total	5.4	5.4			5.4	21.6					
Cost	511	579			320	1915					

Exhibit Of Expenditures APRIL

Tasks	Sanford	Bostrom		Secretary	Fringe @ 23.4%		Research Ass'ts	Consultants		Material Supplies	Equipment	Travel		Overhead @ 55.3%					Total
Focus Group	2713	976		498	863		5315			50		626		6106					17147
Building Survey	347	1286		142	382		1807			170				2286					6420
Controlled Observation																			
Structual Observation																			
Criteria for Use																			
Total	3060	2262		640	1245		7122			220		626		8392					23567

Figure 12 Monthly Progress Report


OVERALL PROGRESS EXHIBIT
APRIL 1985
percent of task complete
100
90
80
70
60
50
40
30
20
10
Focus Groups
Building Survey
Controlled Observ.
Structural Observ.
Criteria
percent of total project complete

Manpower Report

(Person Days) PROJECTED FOR MAY

Tasks / Personnel	Sanford	Bostrom			Secretary	Research Assts.					
Focus Group											
Building Survey	5.4	5.4			5.4	21.6					
Controlled Observation											
Structural Observation											
Criteria for Use											
Total	5.4	5.4			5.4	21.6					
Cost	511	579			320	1915					

D-49-678

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
ATLANTA, GEORGIA 30332

COLLEGE OF ARCHITECTURE
RESEARCH PROGRAM
(404) 894-3476

MEMORANDUM

D48-678

TO : Ed Steinfeld

FROM: Jon Sanford and Jim Bostrom

DATE: May 28, 1985

PROGRESS REPORT

Hand Anthropometrics Project

May 1985

The principle activity for May has been the conduct of the building survey. To date eighteen of the twenty buildings have been surveyed. We expect to complete the other two buildings by June 5th. The following buildings have been included in the survey:

POTENTIAL SURVEY SITES (Atlanta)*

1. Civic
   a. Civic Center
   b. Georgia World Congress Center

2. Community Center

*3. Library
   a. Dowtown Atlanta Public Library

*4. Post Office
   a. 14th Street

5. Hospital
   a. VA Medical Center, Decatur, Ga.

6. Educational
   a. Secondary School
   ***b. College Campus - Georgia Tech Student Center

7. Stadium/Arena
   * Fulton County Stadium
     OMNI Arena

8. Municipal Buildings
   *a. Decatur Courthouse
   *b. Russell Federal Building
   *c. Atlanta City Hall

9. Museum/Zoo
   a. High Museum
   b. Atlanta Zoo
   c. Toy Museum

10. Transportation Facilities
   *a. Airport
   *b. MARTA Station
   *c. Train Station
   d. Bus Terminal

11. Park/Play Area
   a. Visitors Centers - Kennesaw
      Stone Mountain
      Chattahoochee
      Chastain

12. Restaurant Chains
   *a. Burger King
   b. D'Lites
   c. McDonald's

13. Theater
   a. Fox Theater
   b. Alliance Theater in Woodruff Arts Center

14. Residence/Institutional Living
   a. Public Housing
      1. Techwood Homes
      2. Clark Howell

   b. Elderly Housing
      1. Wesley Woods
      2. Juniper Arms
      3. Roosevelt House

   c. Nursing Homes
      1. VA Medical Center Nursing Home

   d. Other Institutional Settings

15. Prisons/Penitentiaries
   Federal Prison
   New Fulton County Jail

16. <u>Commercial Buildings</u>

a. Shopping Malls
   *1. Lenox Square
   2. Gwinnett Place

b. Department Store
   1. Rich's
   2. Davisons
   3. Sears
   4. J. C. Penny

c. Mixed Use Development
   *1. Omni
   2. Colony Square

d. Office Buildings
   *1. Fidelity National Bank
   2. Georgia Tech Research Institute

17. <u>Hotels</u>

a. Omni
b. Peachtree Plaza
c. Hyatt Regency
d. Marriott Marquis (new)

*Surveyed

During June the data from the survey of buildings will be analyzed. We expect that the survey will be complete by the end of June.

During June several personnel changes will occur. The graduate students working as GRA's will leave the project and Jim Bostrom will be leaving Georgia Tech at the end of June to take a job with Barrier Free Environments in Raleigh, N. C. Jon Sanford will continue as Project Director for the duration of the project.

Manpower Report

(Person Days)

MAY

Tasks / Personnel	Sanford	Bostrom			Secretary	Research Assts.					
Focus Group											
Building Survey	5.4	5.4			5.4	21.6					
Controlled Observation											
Structural Observation											
Criteria for Use											
Total	5.4	5.4			5.4	21.6					
Cost	511	579			320	1915					

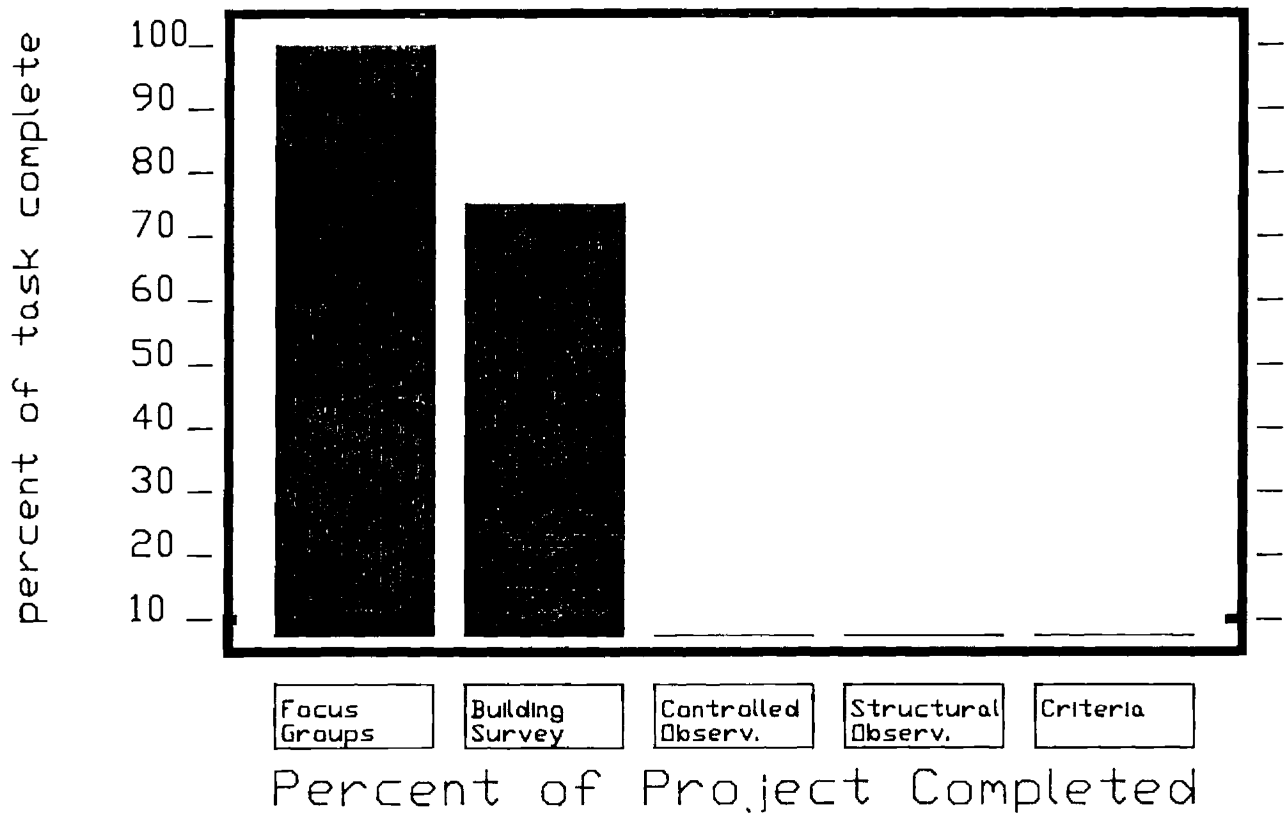
Exhibit Of Expenditures

MAY

Tasks	Sanford	Bostrom	Secretary	Fringe @ 23.4%	Research Ass'ts	Consultants	Material Supplies	Equipment	Travel	Overhead @ 55.3%	Total
Focus Group	2713	976	498	863	5315		50		626	6106	17147
Building Survey	858	1865	462	637	3722		245			4307	12096
Controlled Observation											
Structual Observation											
Criteria for Use											
Total	3571	2841	960	1500	9037		295		626	10413	29243

Figure 12 Monthly Progress Report

OVERALL PROGRESS EXHIBIT
May 1985



Manpower Report

(Person Days)

PROJECTED FOR JUNE

Tasks / Personnel	Sanford	Bostrom			Secretary	Research Assts.					
Focus Group											
Building Survey	5.4	5.4			5.4	21.6					
Controlled Observation											
Structural Observation											
Criteria for Use											
Total	5.4	5.4			5.4	21.6					
Cost	511	579			320	1915					

project status report

D-48-698

Name [illegible] Date 11 [illegible] 85

Project [illegible]

Developments All [illegible] in the Atlanta [illegible] have been [illegible]. Data has been [illegible] and entered into the computer [illegible]

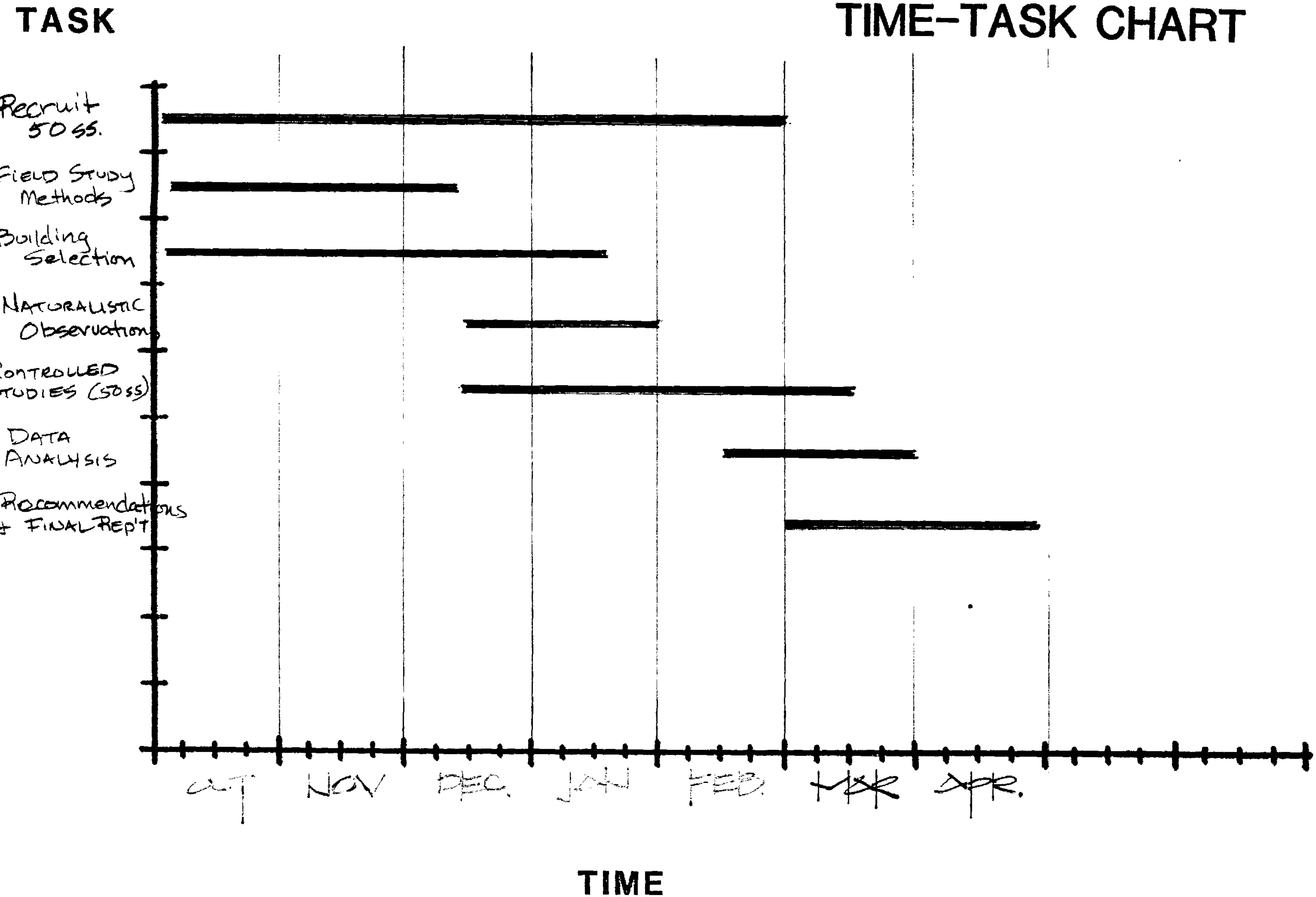
Status Preliminary [illegible] of data [illegible] location and frequency of [illegible] devices. Data will be used to [illegible]

Next Step(s) [illegible] information + preliminary [illegible] test [illegible] arrangements for [illegible] test.

Comments REVISED BUDGET + TIME LINE ARE ATTACHED TO REFLECT NEW PROJECT COMPLETION DATE OF APRIL 30 1986. ACCORDING TO CURRENT BALANCE AND WORK TO BE DONE, WE APPEAR TO BE ON TARGET FOR THIS COMPLETION DATE (BARRING ANY UNFORSEEN [illegible] SUCH AS BOSTROM COMING BACK!)

Figure 9 Monthly Report Form

TIME-TASK CHART



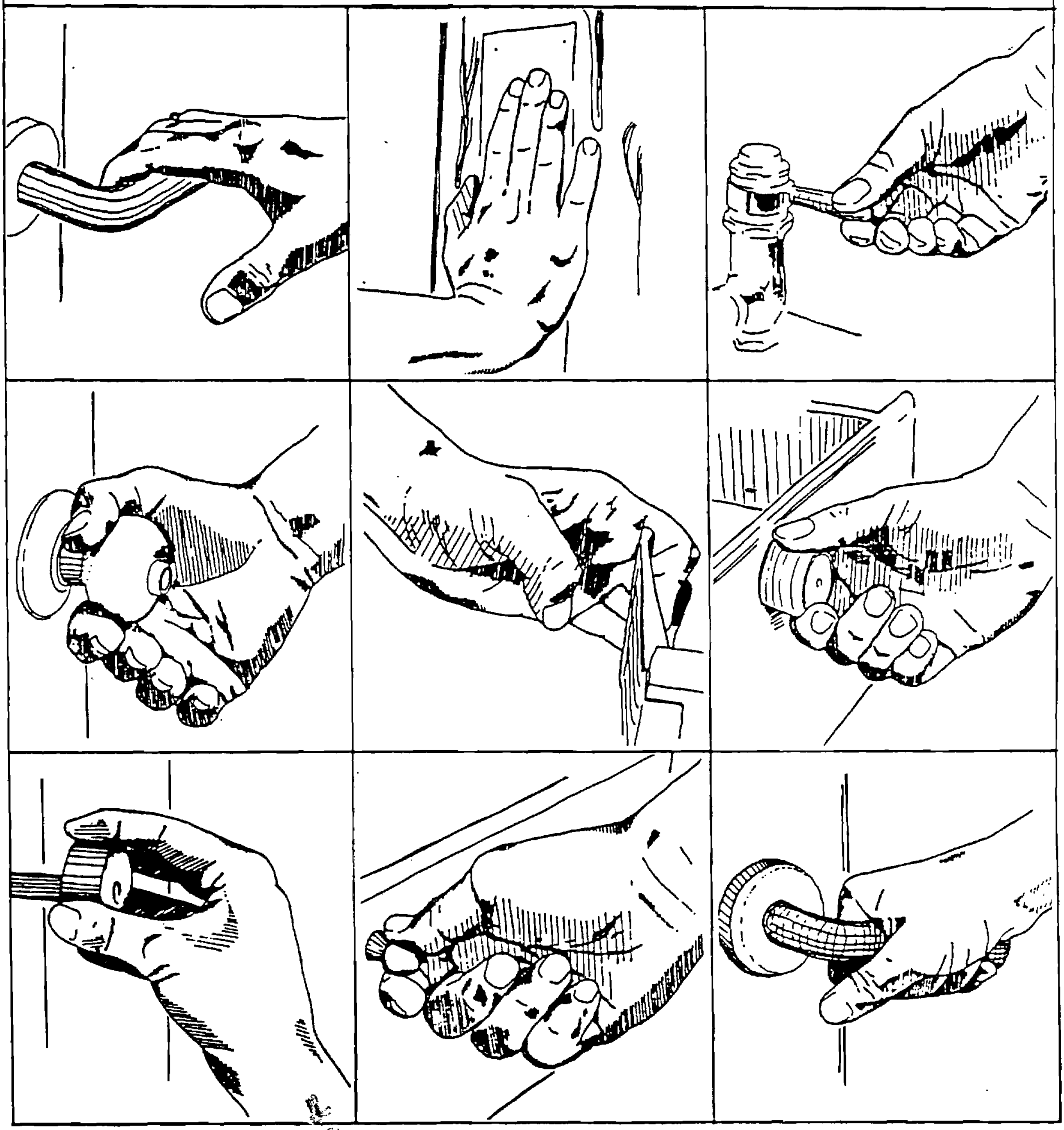
REVISED BUDGET

Personal Services

P.I. (Jon Sanford @ .5 EFT Nov.-April)	$ 7,248
Research Scientist (@ .25 EFT Jan.-April)	2,417
Secretary (@ .25 EFT Nov.-April)	2,520
GRAs	
2 - (Oct.-Dec. and April)	4,992
4 - (Jan. - March)	7,488
	24,665
Fringe (@ 21% on all but GRAs)	2,559
TRAVEL	5,784
M&S	6,000
	$39,008
OH (@ 63 .5)	$24,770
TOTAL	$63,778
Unencumbered Expenses (PI July-Oct.)	2,416
	$66,194
FREE BALANCE AS OF 9/30/85	$68,009

Hands On Architecture: VOL. 1
Part Two - Field Research

Adaptive Environments Laboratory
School of Architecture and Environmental Design
SUNY at Buffalo
Final Draft



Final Report
1/23/87

HANDS ON ARCHITECTURE, VOL. 1, PART 2:

FIELD RESEARCH

College of Architecture
Georgia Institute of Technology
Atlanta, GA 30332
404/894-2069

Report Prepared by:

Author

Jon Sanford

Data Analysis

Jaepil Choi

Illustrations

Hui Min Chen
Cathy Magnan
Michelle Tragesar
Jon Sanford

Project Staff

SUNY/Buffalo

Edward Steinfeld, Arch.D.
Professor of Architecture
Project Director

Marcia Feuerstein. M.Arch.,OTR/L
Visiting Assistant Professor
of Architecture
Research Coordinator

S. George Schiro, Ph.D.
Assistant Professor of
Industrial Engineering
Co-Principal Investigator

Research Assistants:

Barbara Kubasti
Karen Rafalko
Carl Nuermberger
Wendy Levine
Louis Carrier
Gary Morog
Bruce Majkowski

Consultants:

David Mandel. Ph.D.
Warren Wake. Ph.D.
Nina Harfmann. OTR

Georgia Institute of Technology

Jon Sanford. M.Arch.
Research Scientist
Co-Principal Investigator

Jim Bostrom. M.Arch.
Research Scientist
Project Associate

Sarah Endicott. OTR/L
Project Associate

Research Assistants:

Hui Min Chen
Jaepil Choi
Jean Yang
Cathy Magnan
Michelle Tragesar

PREFACE

The Hand Anthropometrics Project was created to develop a data base for designing products that are used in buildings and intended to be manipulated by hand. This data base is focused on the abilities of physically disabled people since there is a lack of human factors design data for this group. As the project developed, it became clear that the use of operable devices and controls is heavily dependent on five factors:

1. approach clearances.
2. reach limits of the arm.
3. anthropometrics of the hand and its grips.
4. biomechanic abilities to exert force and form grips.
5. psychomotor skills.

Hands-On Architecture is the final report of the project. It is organized into three volumes. Volume One is the main research report. It summarizes the literature review and presents a conceptual framework that was used as a means of organizing the research and communicating the findings. Volume Two is a design guide that presents a method and data for improving design of buildings through consideration of hand and arm abilities of disabled people. Volume Three is a set of recommendations for enforceable guidelines and requirements that can improve building regulations on this topic.

TABLE OF CONTENTS

INTRODUCTION

Laboratory testing has several drawbacks, the most significant of which is that it sets up a hypothetical, ideal case. At best, it simulates the real world and at worst, it ignores reality. The laboratory is best utilized to develop data gathering techniques and to undertake physical measurements as proposed in this project.

On the other hand, controls, devices and other mechanisms are rarely used in a Skinner box. They are, in fact, implements which are intended to facilitate the use of the designed environment and as such, they should be studied in the context in which they are used. Moreover, because the context and ambient conditions in which controls and devices are found vary from building to building (i.e., the height of a switch, the location of elevator controls, the size and weight of a door, the slope of a handrail, the number of people who use a facility, the temperature etc.) the design of the environment greatly influences hand position, force required to operate a mechanism, arm reach, etc. As a consequence, it is imperative to study use of design features in different contexts.

In general, there are a number of factors which affect the ability to perform a task. As illustrated in Figure 1 these factors can be inherent either in the nature of the object or in the way the object is used by an individual. In turn, problems due to the object may result from either the design of the device itself (e.g. its shape, size or texture which may make it difficult to grab); the design of the equipment on which the device is located (e.g. the location of a slot or button too high for a non-ambulatory person to use) or simply the design of the environment which precludes an individual from reaching the device (e.g. obstructions under a sink which prevent a wheelchair-bound person from getting close enough to the faucet). More specifically (as Figure 1 illustrates), each of the three levels of environmental factors has an impact on each stage of the operation required for successful task performance. In other words, the variables associated with the setting, the equipment and the device affect one's approach to the device (e.g. can I get close enough?), operation of the device (e.g. do I have enough force?) and departure from the device (e.g. can I get through before the door closes on me?).

Therefore the purpose of conducting field research was to gather data on both the physical environment as a whole (setting, equipment and device) and the way in which the environment is used (approach, operation, departure) in order to be able to better understand where and why problems occur in this interface.

Field Research involved two primary tasks:

- o Task I: Naturalistic Studies,
- o Task 2: Controlled Field Testing.

Naturalistic studies entailed observing the use of various controls and devices by users of existing buildings. In this way laboratory techniques were able to be validated and a baseline was established against which the results of the controlled testing were compared. In the controlled field testing test subjects were brought to the 5 buildings selected for Phase I and were observed using the same devices studied in the Naturalistic Phase.

OBJECT ↓ / MAN →			SEQUENCE OF ACTIONS		
			APPROACH	OPERATING	DEPARTURE
PHYSICAL DESCRIPTION	SETTING	•Location •Environmental Conditions	•Accessibility	•Visibility	•Safety
	EQUIPMENT	•Position of Control •Frequency of Use •Number of Manipulations	•Accessibility	•Position of Body (Convience,comfort)	•Ease of Departure
	DEVICE	•Size •Shape •Color •Precision •Complexity of Operation •Texture •Response •Output	•Functional Ability (Which limb/joint is required to operate.)	•Force required to operate •Dexterity of Hands/Fingers/Joints	•Sequence of Actions (Part of a sequence of actions or solitary event)

Figure 1. Relationships Between the Environment and Device Operation

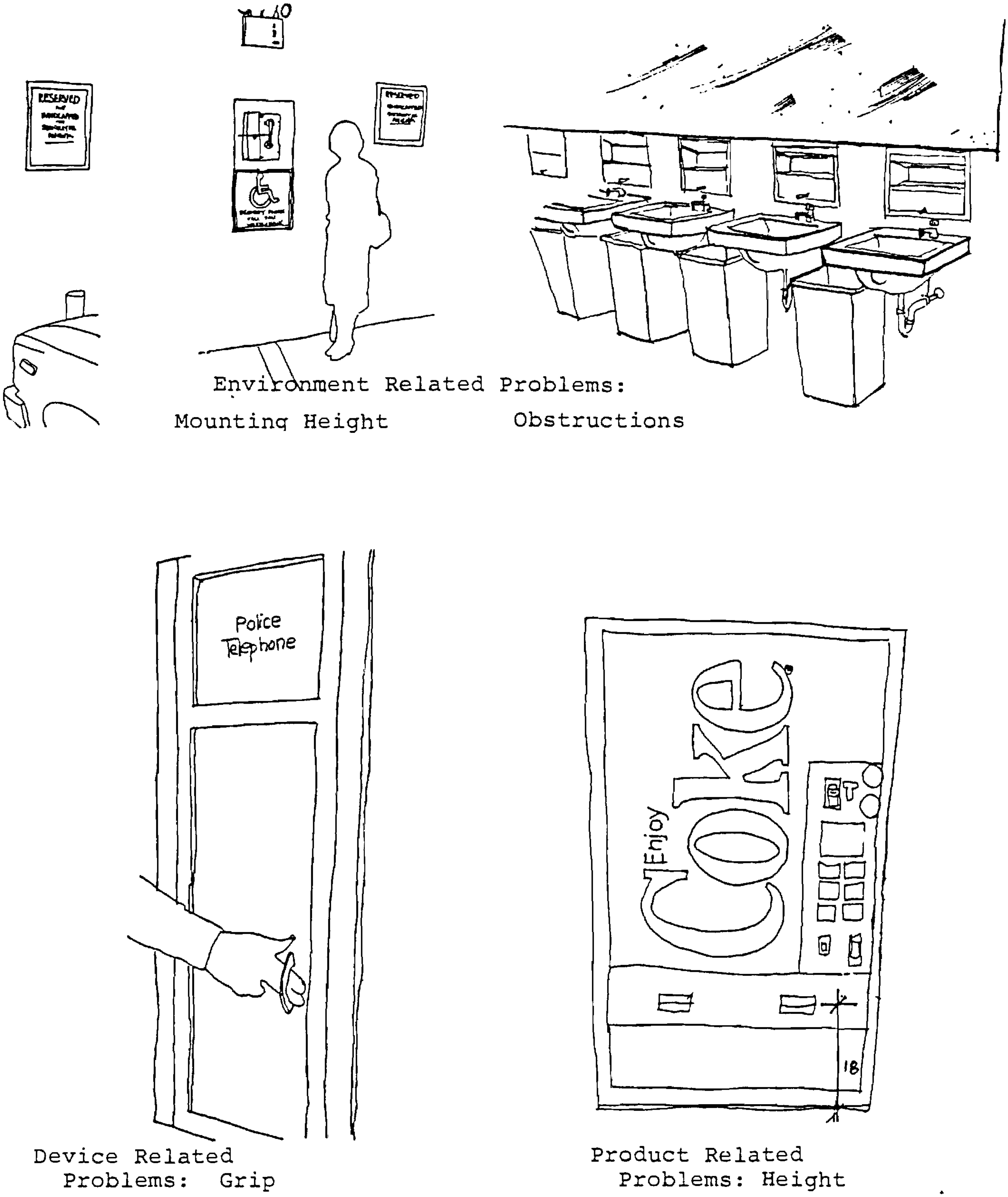


Figure 2. Design-Related Problems

PROJECT FOCUS

In order to narrow the scope of the project from a study of all mechanisms operated by the hand and to better define the focus of the field research, two tasks were undertaken prior to the field testing: Focus Group Discussions and a Building Survey. The former was intended to set up general guidelines and criteria for device selection. The purpose of the latter was to determine which types of devices (within the guidelines set by the Focus Groups) occurred most frequently and how many different types of devices were actually found in buildings. Based on this information, specific devices and sites were chosen for testing.

Focus Group Discussions

The focus group discussions provided an opportunity for both disabled consumers and experts to describe their experiences in the operation of various controls, devices etc.; to alert the researchers to specific problems, dysfunctions or hazards; and to recommend devices and sites for field testing. Each workshop meeting included 6-10 people including members of the research team. Those participating included disabled consumers of all ages and types of hand related problems, rehabilitation professions (such as occupational therapists and physical therapists), medical researchers, human factors specialists and physicians (see Focus Group Report, Appendix A.) Two focus groups were held in Atlanta, Ga. and one in Buffalo, N.Y.

There were several products resulting from the workshops. First, a list of criteria was generated for prioritizing the devices on which the field research should focus.

These criteria included:

1. Activities that are necessary or are performed frequently;
2. Devices located in publicly accessible buildings;
3. The degree of difficulty of use; and
4. Devices that can be operated by simple, easy to carry adaptive devices.

Second, the Focus Groups suggested a list of equipment which should be included in the study. Generally these equipment recommendations can be categorized into 3 types of activities: Those that are used for personal hygiene (e.g. toilet, sink, etc.), communication (e.g. mail box, telephone) and circulation/egress (e.g. doors, public transit turnstiles, etc.).

Finally, the Focus Groups suggested criteria for subject selection such as degree and frequency of impairment, use of mobility aids etc. These were incorporated into the subject pool survey.

Building Survey

In order to narrow the broad guidelines for the selection of devices for testing which was established by the Focus Groups, a building survey was conducted. This task was designed to provide information on the physical characteristics of the various devices used for Communication, Circulation/Egress and Personal Hygiene which are commonly found in publicly accessible buildings.

The survey consisted of building walk-through inspections, during which each different type of operable control was photographed, catalogued and described in physical terms. Using the user/environment matrix described previously (see Figure 1) as a model for the Building Survey, the physical data collected actually included not only information on the devices themselves (see Figure 3), but on the context as well (i.e. the equipment on which the device was located and the setting in which the equipment was found). In addition, the survey noted the impacts that these three levels of environmental design (device, equipment, setting) had on the use of the device (approach, operation and departure).

Specifically, the description of the setting focused on factors (such as lighting levels) that modify the task of using devices. For example, many controls require accurate visual feedback in order to know if they have been used properly (i.e. being able to see on elevator button light up when pushed). If the lighting level is too low or in some cases too high, there may not be enough feedback for the user to know if the device has been actuated. In addition, both the setting and the equipment often determine whether a device can even be used at all. If a wheelchair cannot get close enough to the piece of equipment because there is no accessible route (such as the omission of a ramp or there is something obstructing the path), or the operating mechanism on a piece to equipment is located out reach (such as a coin slot on a phone or stamp machine) then having an device which is operable makes no difference. As a result, the purpose of the building survey was to gather data on the physical characteristics of the devices as well as the modifying contextual factors.

Twenty-three buildings (of which 5 were eventually chosen for the field testing sites) were surveyed in Atlanta, Georgia. In order to develop a database with as broad a range and representation of types of devices, equipment and settings (both accessible and inaccessible), buildings surveyed varied in age, occupancy type and functional use. The buildings surveyed included:

1. Federal Buildings
    a. Fourteenth St.
    b. Civic Center
    c. Richard B. Russell Federal Building

2. Educational (College)
    a. Georgia Tech Student Center
    b. Georgia Tech College of Architecture
    c. Georgia Tech College of Management

3. Institutional
    a. Veterans Administration Medical Center (Decatur)
    b. Shepherd Spinal Center
    c. Emory University Rehabilitation Center
    d. Wesley Woods Elderly Housing
    e. Veterans Administration Nursing Home (Decatur)

4. Municipal Buildings
    a. Decatur Courthouse
    b. Atlanta City Hall

5. Library
    a. Downtown Public Library

6. Sports Arena
    a. Atlanta Fulton County Stadium

7. Transportation Facilities
    a. Atlanta Hartsfield International Airport
    b. Metropolitan Atlanta Rapid Transit Authority (MARTA) Rapid Rail Station (North Avenue)
    c. Brookwood Train Station (AMTRAK)

8. Restaurant Chain
    a. Burger King (Northside Drive)

9. Theater
    a. Fox Theater

10. Shopping Malls
    a. Lenox Square
    b. Omni International

11. Office Building
    a. Fidelity National Bank (Decatur)

Results. The devices inventoried in the building survey were grouped into six categories:

1. Electric Controls (e.g. elevator buttons),
2. Power Grip Handles (e.g. door pulls),
3. Precision Grip Handles (e.g. towel dispenser handles),
4. Receptacles (e.g. coin slots),
5. Dispensers (e.g. stamp machine),
6. Assist Devices (e.g. handrails).

Hand operated devices come in all shapes and sizes. As a result, there was a great disparity in the physical dimensions among the six categories. For example, the distance a device was located from the mounting surface ranged from 17 mm (.67 in.) to 166 mm (6.54 in.); major cross sectional length varied from 30 mm (1.17 in.) to 251 mm (9.87 in.); and height from the floor which ranged from a high of about 1143 mm (45 in.) to a low of around 356 mm (14 in.).

Power grip handles were the most common devices, accounting for 43% of all the devices inventoried and occurring with a frequency almost three times greater than electric controls, which were the next most common category. However, although power grip handles were the most frequent types of devices found, the bar shape, which comprises the majority of the power grip group, accounted for only 33% of the grip shape types, while the area grip shape (receptacles, dispensers and push-type devices) accounted for 42% of the grip shape types. The plate shape comprised 19% and the spheroid was an almost negligible, 6%.

Table 1 summarizes the physical measurements collected on the devices which fall within these categories. See also Appendix F for more detailed information on each of the individual devices which were catalogued.

Table 1. Mean Values for Devices Inventoried In mm (inches)

Variable	Electric Control (n=49)	Power Handles (n=143)	Precis. Handles (n=25)	Recept. (n=25)	Dispens. (n=11)	Assist Device (n=37)
Distance from mounting surf.	17 (.67)	63 (2.47)	43 (1.68)	NA	74 (2.90)	166 (6.54)
Major cross section	30 (1.17)	234 (9.22)	36 (1.40)	193 (7.59)	251 (9.87)	151 (5.93)
Minor cross section	29 (1.13)	353 (1.39)	16 (0.63)	88 (3.46)	99 (3.91)	52 (2.03)
Circum-ference	NA	234 (9.21)	74 (2.93)	NA	NA	204 (8.03)
Height from floor	1159 (45.63)	1014 (39.94)	1076 (42.35)	1053 (14.44)	1134 (44.66)	897 (35.30)

BUILDING SURVEY		DESCRIPTON OF USE		
	PHYSICAL DESCRIPTION	APPROACH	OPERATION	DEPARTURE
SETTING BLDG: TYPE: FLOOR: RM. NO. :	AMBIENT CONDITION: Temperature Lighting Acoustics Precipitation	Accessibility *entrance: *route:	Accessibility: *equipment: Visibility:	Safety *egress:
EQUIPMENT MODEL: TYPE:	NO.of Devices; Type of Devices: Task Sequence:	Accessibility *distance fr. body:	Posture *seated: *standing upright: *standing bending over: *Other:	Ease of Departure *balance stable: *balance unstable: *fall:
DEVICE TYPE	Position: Dist. fr. fl. Mount. surf. Spacing Other Size: Surface Area: Grip Dimension: Color: Shape: Material: Surface Texture: No. of Manipulation:	Functional Requirements *upper arm *lower arm *hand *unilateral *bilateral *ambilateral Preceeding Task:	Force Required (lbs.) *push: *pull: *rotational: Range of movement(inchs) *push: *pull: *rotational: Grip Characteristics *primary: *alternative:	Task Sequence *subsequent task:
SITE	Id. No. Location			SHEET No.

Figure 3: Building Survey Data

PHASE 1: NATURALISTIC STUDIES

The basic approach to the Georgia Tech field testing was to establish two research conditions--naturalistic conditions and controlled conditions. Naturalistic testing entailed unobtrusive observations of building users at the 5 experimental sites. The purpose of this was to gather baseline data on the operation of various devices by a random sample of individuals who were familiar with the facilities. By examining building use under actual conditions, laboratory measures were able to be validated, differences in the use of specific types of control mechanisms noted and problems resulting from the differences in the context assessed.

The five experimental settings in Atlanta were a subset of the 23 buildings inventoried in the Building Survey described earlier. The sites were selected to maximize both the potential use by disabled (especially hand-impaired) persons as well as the types and number of the controls, devices, etc. which were identified by the focus group and building survey research as being problematic for persons with hand disabilities.

Naturalistic observations involved no intervention at the research site. Baseline data on the ability to use specific hand-oriented devices and mechanisms in buildings were obtained by stationing observers to record the behavior of general building users in the experimental sites. Naturalistic observations were made on a time sampled basis in order to account for changes in temperature, lighting levels, number of users (e.g. rush hour vs. off-peak hours in a rapid rail station), etc. which might affect one's ability to use certain devices.

The observations were focused on three primary areas of concern: 1) Approach to the device, 2) Use of the Device and 3) Departure from the Device. Data was gathered on: 1) the user (sex, approximate age, gait, hand problems etc.), 2) problems with using the device which resulted from the environment and 3) problems with using the device which resulted from the design of the device.

Sampling Plan

A random selection of people found at the sites during the observation periods were observed. Since some of the sites could potentially be used by both non-handicapped and handicapped people on an everyday basis, the naturalistic observations at those sites provided the opportunity to compare performance of non-handicapped with handicapped people without the intervention of the researchers.

The naturalistic studies required a time sampling plan to insure that the findings were not confounded by uncontrolled transient conditions such as light levels and temperature. All of the naturalistic testing took place at similar times of day at each experimental site. This controlled for the effects of activity sequences, congestion (i.e., at a train station) temperature, lighting and other transient environmental effects on physical abilities.

Each observer studied the use of each device for at least one hour per day. In order to account for differences in use (e.g. peak hour usage of a transit station) and subjects (e.g. there may be certain days or times when a higher proportion of elderly people use a particular facility), the time of day at which each device was observed was staggered. For example, the turnstile at the North Avenue transit station might have been observed from 8:00-9:00 AM on Monday, 9:00-10:00 AM on Tuesday, 10:00-11:00 AM on Wednesday and so on. Each site was observed for a minimum of one week. Unfortunately, because of the low level of use of some of the devices (e.g. the storage closets at Shepherd Spinal Center were rarely ever used), the number of observations range from almost none to 60 per device.

Site Selection

Five experimental sites located in Atlanta were chosen from the 23 sites surveyed in the Building Inventory. Because of the need to maximize the number of hand-impaired persons as well as other disabled and able-bodied persons in the naturalistic observations, the test sites included one health care/institutional facility. In addition, in order to maximize the range of equipment studied (in terms of age, design, type and degree of accessibility provided) both new and old as well as different building types (e.g. educational, civic, and public) were selected. The buildings selected included:

1. College of Architecture Building, Georgia Tech: The new wing (completed 5 years ago) offers basic accessibility features such as large wing handled faucets on sinks, grab bars in toilet stalls (although the stalls are only 914 mm/3 feet wide) and lever handled drinking fountains. The old wing (c. 1950's) has no special handicapped features.

2. College of Management Building, Georgia Tech: This was the last classroom building built at Georgia Tech (completed 2 years ago) and is the most advanced in terms of accessible design. It features power assist doors, 1524 mm (5 feet) wide toilet stalls with grab bars, wing handled faucets, entrance ramp etc.

3. North Avenue Rapid Rail Station (MARTA): With the system still under construction, MARTA is one of the newest rapid rail transit systems in the United States. The North Avenue Station was completed 2 years ago and has an accessible elevator, assistance phones and a special wide fare gate for wheelchair access.

4. Civic Center Post Office: Originally the 14th street Post Office was selected as a test site. However, when a majority of the test subjects turned out to be non-ambulatory the site had to be changed because the 14th Street Postal Facility requires the ascension of 3 steps to enter. Although the Civic Center Station did not have many adaptable features, it was, nonetheless, all on one level.

5. Shepherd Spinal Center: This is one of the most advanced centers for the rehabilitation of spinal injury patients in the United States. Based on existing knowledge and codes, the building is highly accessible.

Device Selection.

Selection of devices for observation in this phase was based on the 3 categories of devices recommended by the Focus Groups as well as the frequency of occurrance which was identified by the Building Survey. All devices in the 5 sites which met these criteria were included unless it was felt that unobstrusive observation would neither be proper as it would be an invasion of privacy (e.g. use of toilets) nor practical as it would be impossible to be unobtrusive because of the design of the space (e.g. bathrooms or elevators).

As a consequence, the devices selected included all those tested in the Controlled Testing (see Phase II, Device Selection) except restroom facilities and elevator floor buttons. It also included 5 stair and escalator handrails (Architecture, Management and MARTA) as well as ingress and egress from all entry/exit doors in the 5 buildings. A total of 42 devices were observed.

Data Collection Methods

Three criteria were used in developing data collection methods for the Naturalistic Studies:

- o a focus on non-reactive methods,
- o ease of data collection, and
- o accuracy of data.

Non-reactive methods are those in which the influence of the research on responses of the subject is negligible. Questionnaires and interviews about attitudes and opinions are inherently reactive methods because subjects respond as much to the characteristics of the interviewer and the wording of questions as they do to the content of the question itself. This phase relied as much as possible on direct observation of behavior and on instrumentation developed in the building survey and the laboratory testing to assess the use of specific devices, controls and implements (see Appendix B Behavior Checklist).

Specifically, the effectiveness of specific environmental features were measured by the following attributes of human performance:

- o the ability to complete a task,
- o ease of use, and
- o the ability to perform in a task without incident.

Results

In general, all of the users observed in the naturalistic studies successfully completed the tasks. This is not to indicate that they did not experience some problems, only that task performance on all devices was 100% successful. Like the subjects in the controlled testing, everyday users of the environments studied had problems with certain devices, particularly entry/exit doors which required greater force to operate than did any of the other devices.

There were two kinds of difficulty associated with door operation; either the door required an unusually large amount of strength to open (e.g. people were observed physically straining to open the door (or) the door closed too fast, often closing on the user as he/she went through the doorway. Because the entry doors at both the Architecture and Management Buildings were extremely heavy, very few of the users were able to open them with one hand. In fact, most used other parts of their bodies to complete the task of getting in or out of the buildings. The fast door closure also contributed to difficulties people had, especially when they were carrying a load in their hands, as is likely to occur at an academic building.

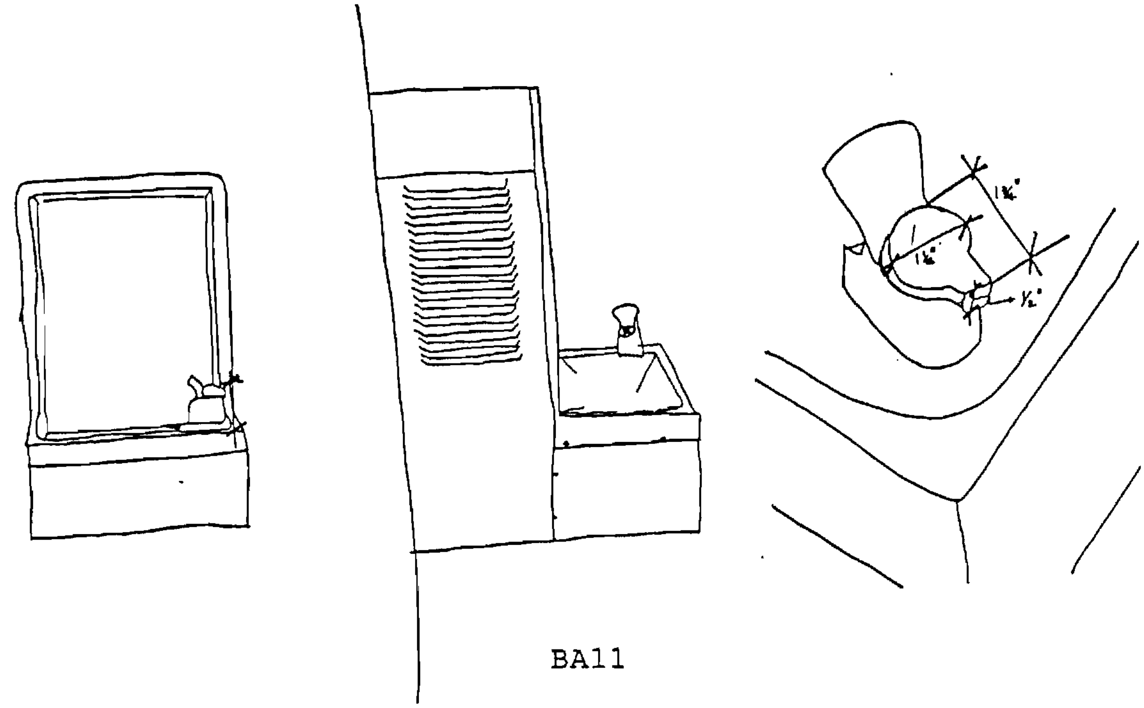
Moreover, the door to the post office had a handle which was 140mm (5.5 inches) higher than the other doors, thus adding potential problems due to the reach factor.

Table 2. Problems Encountered with Doors

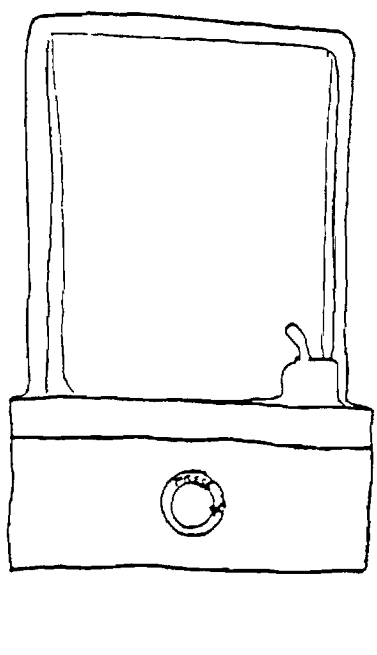
Building/Device	n observations	closure problems	strength problems	total problems (% of n)
1. Architecture				
push bar (ACI)	23	8	3	47.8
door pull (AA19)	39	0	5	7.8
door pull (AC19)	23	8	0	34.8
2. Management				
door pull (BA4)	33	0	10	30.3
push bar (BA6)	19	0	8	42.1
3. Post Office				
door pull (YA1)	43	13	0	30.2

Other problems with individual devices included: 1) difficulties with the lever handle on the water fountain in the Management building (BA11), which, because of its small size was hard to grab and as a result several individuals had their hands slip off, forcing them to re-try the device; 2) the water fountain button at Shepherd Spinal Center (QD1), which, because of its location on the front of the fountain, made it awkward for users to get to the water while pushing the button; and 3) the elevator call buttons at Shepherd (QB4), which, not having a light to indicate that they had been activated, caused users to push the buttons repeatedly to assure that the signal had indeed been sent.

In general, however, most of the devices observed appeared usable with little difficulty by typical users. Furthermore, all were able to be used even if they required more than one attempt to do so. However, as the controlled testing will show, the hand impaired subjects had problems with many of the same devices as did the able-bodied population, only because of their limitations, their difficulties were more severe.



BA11



QD1

Figure 4. Devices which caused problems in Natualistic Studies

PHASE 2: CONTROLLED TESTING

Controlled testing took place in two phases. During the first phase, the main subject sample of hand-impaired individuals were tested at the 5 test sites. In the second phase, a subsample of individuals with disabilities other than hand related problems was tested at the same sites. The purpose of this was to assess whether problems encountered with specific devices were hand related or were a result of subject disabilities in general. The same tasks performed by the main subject sample were also performed by the subsample group.

Subjects

Ideally, the sample of research subjects, for both laboratory and field testing, should represent the full range of abilities of people with hand impairments in the same proportions as those that exist in the total population. However, there existed no comprehensive and standardized survey of abilities for the population at large; nor was there a reliable, standardized method for assessing abilities in a objective manner.

As a result, an approach that provided a reasonably diverse sample was developed. This approach consisted of the following steps:

1. Recruit as many individuals as possible for a subject pool;

2. Make an initial selection of research subjects for the testing to reflect the range of abilities of persons in the subject pool.

3. Continuously add to the subject pool over the course of the research project;

4. Analyze data on the range of abilities for the entire subject pool throughout the course of the research project, and augment, as necessary, the experimental sample to assure a more accurate presentation of the range of ability levels.

To assess functional abilities, the same self-reporting type of interview used in the Buffalo laboratory research was implemented for the field testing in Atlanta. The research team made telephone contact with the individuals who had responded to the calls for participation and interviewed these volunteers using the self inventory questionnaire. The information gathered during the interviews was analyzed and the experimental sample was selected from the subject pool in order to obtain the most seriously disabled people.

<u>Availability of Persons with Hand Impairments</u>. A major problem in subject selection is the availability of people with hand and arm impairments. In many studies using disabled persons as subjects, the sources of subjects were organizations and educational institutions which provided services to the disabled. Subjects from residential institutions were not desirable because of the dependency engendered by the institutional environment, which can bias the subject's performance. Training programs have similar limitations. Rather than relying on one organization as a sole source of research subjects which can result in physical or social biases, a community-wide recruitment program was developed. This insured that the sample would represent people with a wide range

of disabilities and be diverse in demographic characteristics.

Over a period of several weeks, letters describing the research and subject requirements were sent out to the Atlanta Center for Independent Living (ACIL) as well as to various agencies and professional services providers in the Atlanta area. The names of many of the agencies and organizations were obtained from listings compiled in previous research studies, from the Atlanta phone book and from referrals from other agencies and professionals. Further referrals were given by project participants during the interview phase of the project (see Appendix E: Agencies Contacted).

Table 3. Sources of Test Subjects

Source	SUBJECT POOL (n)	EXPERIMENTAL SAMPLE (n)	SUBSAMPLE (n)
ACIL newsletter	21	13	3
Radio	16	11	0
Referral by friend	9	5	1
Cerebral Palsy Center	8	4	0
Atlanta District OT newsletter	5	2	0
Milestones (MD Assoc. newsletter)	3	2	0
Agency letters	3	1	0
MS Bulletin (MS Assoc. newsletter)	2	1	0
Old files	2	1	0
Assoc. Paraplegics Newsletter	1	1	0
GA Tech Newspaper	1	1	0
Atlanta Newspaper	1	1	0
Vocational Rehabilitation	1	0	1
Source unknown	6	3	0
TOTAL	79	46	5

In addition, a major effort was made to obtain exposure in the local media. The Georgia Tech News Bureau sent memo releases publicizing the project and the need for volunteers to the Atlanta daily newspapers, public service announcements were aired on 10 Atlanta radio and four television station including the Cable News Network, and the Cable Television Public Service Station. An article about the project was published in the Georgia Tech campus newspaper. Finally, announcements appeared in 5 local newsletters.

Subject Selection. There were a total of 85 people who initially expressed interest to in the project. Upon follow-up to give the qualifying interview, several volunteers could not be reached, had lost interest or clearly did not qualify. As a result, a total of 79 people were interviewed.

When contacted, the research staff described the nature of the research activities to the volunteer, indicated that every subject would be paid for their time ($40.00/visit) and answered any questions. Subjects were also told that transportation would be provided if needed, even for people who used wheelchairs. A uniform format for conveying this information to the volunteer was developed and the same telephone interview developed in Buffalo was utilized for subject qualification and screening in Atlanta.

Possible participants were interviewed prior to field testing. The primary criterion for subject selection was the manifestation of a hand or arm impairment (regardless of degree of severity) in at least the dominant hand. Consideration was also given to the type of disability and the charactertistics likely to be exhibited as a result of the disability (e.g. although multiple sclerosis victims have relatively good hand function, they were not all good candidates due to their lack of strength and stamina). Nonetheless, people were not selected if their disability was so severe, that it hindered their ability to complete the tasks.

Table 4. Reasons Volunteers Not Selected From Subject Pool

Dominant hand not involved	11
Weather too hot	4
Out-of-town during test phase	3
Unable to contact	1
Withdrew/insurance problems	1
No hand or arm problems	1
Unable to schedule during test phase	1
Too young	1
Inappropriate disability	1

After a total of 51 qualified subjects were identified, they were scheduled for testing and their transportation needs determined. Although there was a slight attrition between the time volunteers were interviewed and scheduled, the problem was minor and 47 people were tested. Moreover, because subjects only had to be scheduled for one test session, the Atlanta testing was not plagued by the "experimental mortality" that was found in the two-session laboratory testing in Buffalo. However, due to the 3-hour length of the test sessions, the extreme heat wave which prevailed during the summer in Atlanta and the stamina problems which many of the disabled subjects have, a number of subjects were unable to complete the testing at all five experimental sites. Moreover, due to problems with testing procedures and data collection methods which had to be radically altered after the first two pretests, the data for those two subjects could not be used. As a result, the number of observations for each device (n) range from 38 to 42.

<u>Sample Description</u>. The controlled testing included a main sample and one subsample of people who were unfamiliar with the test environments. The main sample included 47 individuals with hand impairments who were selected from the subject pool of 79 volunteers. The second was a group of five (5) disabled individuals who had gait problems but did not have hand or arm problems. This included people who use walking aids and have impairments of gait. The subsample was tested to determine if problems encountered with the devices are inherent in the design of a particular feature or whether they resulted from either an

individual's hand disability or the manner in which disabled individuals operate hand controls.

In general (see Table 5), females not only outnumbered males in the subject pool by a ratio of almost 3:2 but this ratio was consistent in both the main and subsamples of test subjects. Most subjects were under 40 years of age and almost 80% used either a wheelchair or some type of mobility aid. In fact, because there were a large number of wheelchair users in the sample, railings and handrails had to be omitted from the testing.

The causes of disability in the subject pool as well as in the two samples were diverse. Cerebral palsy and multiple sclerosis were most prevalent, being reported by 23% and 13% of the volunteers in the two samples, respectively. The only other groups in the subject pool of any significant size were spinal injury (10%) and arthritics (9%). The main subject sample was similar in makeup, with cerebral palsy and multiple sclerosis accounting for the disabilities of 40% of the subjects' tested. Because of the diverse nature of the subjects disabilities, a large majority of the subject pool had disabilities in addition to hand and/or arm problems.

None of the subjects in either of the experimental samples lived in an institution, although several who had cerebral palsy attended day programs for adults. Finally slightly over half of the people in the subject pool reported using some type of adaptation to compensate for their disabilities. The most common of these were grab-bars, reacher sticks, telephones and door openers.

The descriptive data indicate that the experimental samples were representative of the subject pool as a whole and that there is no evidence that the people who did not participate had different characteristics (disabilities and/or abilities) than those who did.

Finally, the data collected on subjects' actual ability to form typical grips indicate that one third of the main sample had difficulty copying the 8 grips when photographs and demonstrations of these grips were shown to them (see Table 7). The most serious difficulty occurred with the disc grip (only 42.6% were able to form the grip). However, only 19% were unable to form either the fingertip pinch or the power grip. The subsample had a 97.5% success rate in forming the eight grips. In fact, of all the grips, only 1 person (see Table 7) had difficulty forming the disc grips.

Table 5. Characteristics of Test Subjects

	SUBJECT POOL N(%)	MAIN SAMPLE n(%)	SUB-SAMPLE n(%)
Sex:			
Male	34(43.0%)	20(43.5%)	2(40%)
Female	45(57.0%)	26(56.5%)	3(60%)
Age:			
Under 20	4(5.1%)	2(4.3%)	1(20%)
20-29	14(17.7%)	6(13.0%)	2(40%)
30-39	27(34.2%)	19(41.3%)	1(20%)
40-49	6(7.6%)	5(10.9%)	0
50-59	10(12.7%)	7(15.2%)	1(20%)
Over 60	10(12.7%)	7(15.2%)	0
Unknown	8(10.1%)	0	0
Disability:			
Cerebral palsy	18(22.8%)	10(21.7%)	1(20%)
Multiple sclerosis	10(12.7%)	8(17.4%)	0
Spinal cord injury	8(10.1%)	4(9.0%)	0
Arthritis	7(8.9%)	3(6.5%)	1(20%)
Stroke	4(5.1%)	2(4.3%)	0
Traumatic hand	4(5.1%)	1(2.2%)	0
Head injury	3(3.8%)	2(4.3%)	0
Muscular dystrophy	2(2.5%)	2(4.3%)	0
Carpal tunnel syndrome	3(3.8%)	2(4.3%)	0
Neuromuscular disease of undertermined type	2(2.5%)	2(4.3%)	0
Spina Bifida	2(2.5%)		2(40%)
Post-surgical problem	2(2.5%)	2(4.3%)	0
Other	14(17.7%)	8(17.4%)	1(20%)
Number of years disabled:			
Less than 1 year	6(7.6%)	4(9.0%)	1(20%)
1-5	17(21.5%)	11(23.9%)	1(20%)
6-10	6(7.6%)	3(6.5%)	0
11-15	4(5.1%)	3(6.5%)	0
Over 15	36(45.6%)	24(52.2%)	3(60%)
Unknown	10(12.7%)	1(2.2%)	0
Ambulatory status:			
Ambulatory	14(17.7%)	8(17.4%)	3(60%)
Use cane or walker	23(29.1%)	19(41.3%)	0
Wheelchair	28(35.4%)	19(41.3%)	2(40%)
Unknown	14(17.7%)	0	0
Right dominance:			
Right	66(83.5%)	39(84.8%)	5(100%)
Left	13(16.5%)	7(15.2%)	0
Disability in:			
One hand	27(34.2%)	12(26.1%)	1(20%)
Two hands	44(55.7%)	34(73.9%)	0
No problems	7(8.9%)	0	4(80%)
Unknown	1(1.3%)	0	0
Disability in:			
Dominant hand	55(69.6%)	43(93.5%)	0
Non-dominant hand	16(20.3%)	3(6.5%)	1(20%)
No problems	7(8.9%)	0	4(80%)
Unknown	1(1.3%)	0	0
Additional disabilities:			
Hearing	18	16	1
Visual	20	17	2
Moving head	20	16	2
Bending, kneeling	44	34	4
Stamina	34	25	3
Balance	45	36	2
Sensitivity	19	17	0

Table 6. Stature of Test Subjects

Main Sample	N	Min	Max	Mean	Median	St. Dev.
Weight in kg (lbs.)	46	35.4(78.0)	113.5(250)	65.0(143.2)	63.6(140)	16.39(36.11)
Shoulder Ht. in mm (in.)						
1. Standing	34	1230(49.2)	1923(76.9)	1645.7(65.8)	1633(65.3)	132.52(5.30)
2. Sitting	43	906(36.2)	1175(50.1)	1017.1(40.7)	1015(40.6)	73.53(2.94)
Shoulder breadth in mm (in.)	45	335(13.4)	495(19.8)	411.5(16.5)	415(16.6)	36.08(1.44)
Arm Length in mm (in.)						
1. shoulder-elbow	46	260(10.4)	405(16.2)	331.3(13.2)	330(13.2)	32.05(1.28)
2. elbow-wrist	46	170(6.8)	365(14.6)	258.6(10.3)	250(10.0)	29.53(1.18)
3. wrist-hand	46	95(3.8)	300(12.0)	188.3(7.5)	190(7.6)	34.58(1.38)
TOTAL LENGTH		552(22.1)	1005(40.2)	779.1(31.2)	778(31.1)	74.54(2.98)
Hand width in mm (in.)	46	75(3.0)	130(5.2)	91.9(3.7)	90(3.6)	11.65(.47)

Subsample	N	Min	Max	Mean	Median	St. Dev.
Weight in kg (lbs)	5	40.0(88)	124.4(274)	64.6(142.4)	54.4(120)	34.22(75.38)
Shoulder Ht. in mm (in.)						
1. Standing	3	1482(59.3)	1709(68.4)	1624.7(65.0)	1683(67.3)	124.23(4.96)
2. Sitting	3	910(36.4)	1010(40.4)	945.0(37.8)	915(36.6)	56.35(2.25)
Shoulder breadth in mm (in.)	5	340(13.6)	520(20.8)	405.0(16.2)	385(15.4)	68.00(2.72)
Arm Length in mm (in.)						
1. shoulder-elbow	5	315(12.6)	380(15.2)	335.0(13.4)	320(12.8)	28.06(1.12)
2. elbow-wrist	5	240(9.6)	285(11.4)	262.0(10.5)	255(10.2)	17.89(0.71)
3. wrist-hand	5	185(7.4)	210(8.4)	199.4(8.0)	200(80.0)	11.04(0.44)
TOTAL LENGTH		745(29.8)	875(35.0)	796.4(31.9)	770(30.8)	54.38(2.17)
Hand width in mm (in.)	5	80(3.2)	100(40.0)	92.0(3.7)	95(3.8)	7.58(0.30)

Table 7. Subjects' Ability to Form Grips

Grip Type Main Sample	Successful Performance n(%)	Partial Performance n(%)	Null Performance n(%)
Power	38(80.9)	4(8.5)	5(10.6)
Disc	20(42.6)	11(23.4)	16(34.0)
Span	32(68.1)	8(17.0)	7(14.9)
Lateral Pinch	35(74.5)	7(14.9)	5(10.6)
Pistol	32(68.1)	7(14.9)	8(17.0)
Hook	29(61.7)	7(14.9)	11(23.4)
Flat/Hand	27(57.5)	4(8.5)	16(34.0)
Fingertip Pinch	38(80.9)	4(8.5)	4(8.5)
Subsample			
Power	5 (100%)	0	0
Disc	4 (80%)	1(20%)	0
Span	5 (100%)	0	0
Lateral Pinch	5 (100%)	0	0
Pistol	5 (100%)	0	0
Hook	5 (100%)	0	0
Flat Hand	5 (100%)	0	0
Fingertip Pinch	5 (100%)	0	0

Device Selection

In narrowing the list of devices from the very general to the specific, the first step was for the Focus Groups to define categories of devices which were felt to be most important and with which hand impaired individuals had the most problems. The three groups targeted were devices associated with communication (telephone, mailbox etc.), circulation/egress (handrails, public transit, doors, etc.) and personal hygiene (toilet, faucet, etc.).

The second step was the Building Survey. This method identified the different types of devices used for the tasks outlined by the Focus Groups and established the frequency of occurrence of the devices. For example, a door could be opened by a push bar handle, a round door knob, a lever handle, a U-shaped pull, etc.

Finally, the Naturalistic Studies established a frequency of use for each of the devices inventoried in the Building Survey as well indicating the devices with which people had problems and those with which they did not.

From these three sources, devices were chosen which:

1) Fit into the three task-oriented categories;

2) Were targeted specifically by the focus groups as being of great importance (e.g. public transit);

3) Occurred most frequently (e.g. door handles, elevator buttons, water fountains); and

4) Featured a range of degrees of difficulty (e.g. devices were "difficult", "average" and "easy".

In addition, the abilities of the test subjects introduced other human factors which influenced device selection. For example, handrails on stairs and escalators had to be omitted because of the predominance of non-ambulatory subjects; drive-through devices such as bank tellers or parking gates were not tested due to the inability of finding enough subjects who could drive; and, because subjects were of both sexes, both male and female restrooms at each site (except the unisex rest room at Shepherd) had to be tested by the appropriate gender.

From the criteria established, the equipment and devices in each of the test sites were as follows:

I. Architecture
1. Telephone (AA4) (Standard, public, touch tone, wall mounted phone)
   a. Receiver (AA4a)
   b. Number Pad (AA4b)
   c. Coin Slot (AA4c)
   d. Coin Return (AA4e)
2. Push bar door handle (AC1)
3. Door pull (AA19)
4. Elevator Call button (AB1) (raised button)
5. Elevator floor button (AB2) (raised button)
6. Water Fountain handle (AD22) (wing type)
7. Rest Room Door Pull (AC19)
8. Toilet Flush Valve (AD34) (accessible stall but only 3' wide)
9. Faucet Handle (AD25) (wing type)

II. Management
1. Exterior Door Pull Handle (BA4) (Power Assist Door)
2. Water Fountain Handle (BA11) (lever type)
3. Rest Room Door Pull (BA12)
4. Toilet Flush Valve (BB24) (accessible stall)
5. Faucet Handle (BA18) (wing type)
6. Elevator Call Button (BA8) (recessed type)
7. Elevator Floor Button (BB31) (recessed type)
8. Push Bar Door Handle (BA6) (power assist door)

III. MARTA Station
1. Elevator Call Button (DB16) (flush mount)
2. Elevator Floor Button (DB13) (flush mount)
3. Assistance Telephone (DC5)
4. Fare card slot (DA7) (Horizontal)
5. Coin Slot (DA6) (Horizontal)
6. Fare Card Return (DA1)
7. Fare gate (DA16)

IV. Post Office
1. Exterior Door Pull (YA1) (door swings in & out)
2. a. Stamp Machine Coin Slot (YA2a) (vertical)
   b. Selection Button (YA2b) (raised type))
   c. Stamp Removal (YA2c)
3. Mail Slot (YA3)
4. P.O. Box (YA4)

V. Shepherd Spinal Center
1. Elevator call button (QB4) (recessed)
2. Elevator floor button (QB5) (recessed)
3. Door knob (QC3) (round)
4. Rest Room Door Pull (QC13)
5. Toilet Flush Valve (QA1) (accessible stall)
6. Faucet Handle (QA10) (wing type)
7. Water Fountain Handle (QD1) (button-type)
8. Door Handle (QC12) (lever-type)
9. Door Push Bar Handle (QC5)

Data Collection

With a few additions to include field-specific data from the Naturalistic Studies, the data coding forms (see Appendix C Field Test Coding) were identical to those developed for the laboratory-based, product evaluation research.

As in the naturalistic studies, observation techniques were the primary form of data collection. However, this phase also utilized self report data from the subjects in order to determine how easily a task could be completed and what level and types of difficulties well encountered while undertaking a task (i.e. how much effort it took to reach for a telephone receiver).

Observed performance was measured by:

1) Task Performance: ability to successfully complete a task
2) Method Used to Undertake a Task:
   - type of grip
   - position of hand or arm relative to body
   - position of body
   - location of hand on control mechanism
   - amount to hand or arm function to complete task
   - use of other body parts (e.g. hips) or other aids to (e.g. wheelchair) to complete task

3) Ability to engage in a task without incident such as:
   - tripping
   - collisions with object
   - slipping
   - loss of balance
   - repeated attempts
   - missed contact
   - hitting object
   - unusually long time to operate
   - poor precision or adjustment

Subjective responses were recorded by the:

1) Amount of perceived energy expended which was rated on scale from almost none (zero) to maximal (10);

2) Amount of perceived discomfort experienced (none, mild or extreme); and

3) Difficulties which were encountered in task performance.

Procedures

At the beginning of the test session a brief description of the project was read to each subject and each was required to sign an informed consent form (see Appendix D: Testing Protocol). After this procedure anthropometric data on each test subject was collected. This included shoulder height and breadth, hand and arm length and weight. In addition, subjects were asked to look at pictures of the basic types of grips and attempt to emulate each of the photographs.

The test for each subject consisted of completing a total of 43 devices in the 5 research sites (which were numbered 1-5). In order to minimize the effects of fatigue on subject performance at the last several test sites, the order of the test sites was varied from test session to test session. At the beginning of each session, a die was rolled to indicate which of the test sites would be the starting point. Each of the buildings was then tested in the same sequence. For example, if a 4 was rolled on the die building number 4 will be tested first, then site no. 5 followed by 1, and so on. (If a six was rolled, the die was re-rolled).

Subjects were tested two at a time and transported to each of the research sites by two members of the research team. At each site the subjects were directed to a number of devices, one at a time, and asked to complete a task using each device (e.g. wash your hands, take a drink of water, or take the elevator to the third floor). After all of the devices had been completed at the test site, the subjects were then transported to the next site, and so on, until each of the 5 sites was completed.

Data coding consisted of a standardized behavior checklist on which the observer could note degree of difficulty, task performance, etc. Each researcher was responsible for recording the performance of one subject. This one-to-one situation not only diminished the possibility of missing something in the subjects'performance, but it also ensured the safety of the subject as well.

Data Analysis

Data from the field research were analyzed in several different ways. The analyses included:

- descriptive data on total sample of devices (including types of grip shapes)
- descriptive data of subjects' performance including posture, grip type and body location;

- comparison of performance of users in naturalistic observations to subjects in controlled testing;
- comparison of observed performance with subjects' self-report evaluation;
- comparison of devices by generic group type;
- comparison of devices by product; and
- analysis of contextual (including both fixed as well as transient environmental conditions) and design factors which impact performance.

Findings

General Results

Performance. In general the overall performance of the subjects on all of the devices tested was good. Of the 1716 attempts at task performance, 1477 (86.1%) were successful and only 239 (13.9%) were unsuccessful. Almost half (21 out of the 43) of the devices were used successfully more than 90% of the time (see Table 10). Moreover, subjects primarily used their hands to complete the tasks. In fact, of the 1477 successful performances, 90.4% were completed by the subjects using only their hands. An additional 6.1% used their hands but were aided by either a wheelchair or some other part of their body (i.e. their hips pushing open a door) and only 3.2% of the tasks had to be accomplished by using some means other than one's hands.

Table 8. Trial Performance

	Complete Operation with hands	Partial Operation with hands	Alternative Method of operation	Null Performance	Total
N Trials	1336	89	55	236	1716
% of Trials	77.8	5.2	3.2	13.8	100%

Although the 3.2% is a small percentage, the majority of those using an alternate method to completely operate a device were wheelchair users who used their chairs (67.3% of the time) to push open doors. In fact (see Table 9), with the exception of two subjects who used their feet to flush the toilets at the Management Building and Shepherd Spinal Center, one who used a stick on a number of devices, and one who used his mouth to remove the Fare Card, the only places where both ambulatory and non-ambulatory subjects used alternate methods for complete operation were on doors which had to be pushed open.

Table 9. Devices Operated Completely by Alternative Methods

		Uses	Type of Operation
1.	Architecture		
	Number pad (AA4b)	1	reacher stick
	Push Bar Door (AC1)	9	wheelchair
	Elevator Floor Button (AB2	1	reacher stick
	Toilet Flush Valve (AD34)	1	reacher stick
	Faucet Handle (AD25)	1	reacher stick
II.	Management		
	Toilet Flush Valve (BB24)	3	foot(2)reacher stick (1)
	Elevator Floor Button (BB31)	1	reacher stick
	Push Bar Door (BA6)	5	wheelchair
III.	MARTA Station		
	Elevator Floor Button (DB13)	1	reacher stick
	Fare Card Return (DA1)	1	mouth
	Fare Gate (DA16)	13	wheelchair
IV.	Post Office		
	Door (YA1)	7	wheelchair
	Coin Slot (YA2a	1	reacher stick
	Selection Button (YA2b)	1	reacher stick
V.	Shepherd Spinal Center		
	Toilet Flush Valve (QA1)	4	foot(2), cane(1) reacher stick(1)
	Faucet Handle (QA10)	1	reacher stick
	Push Bar Door (QC5)	1	wheelchair
	TOTAL	52	

Finally, although 239 (13.9%) of the tasks attempted were unsucessful, over 40% of those resulted from the subjects' inability to reach the device (i.e. the coin slot on the telephone or the flush valve on the commode). These were problems which were caused by the context in which the devices were located (i.e. the telephone was too high or the toilet stall too narrow) rather than by the design of the device itself. In addition, reaching problems tended to affect primarily the non-ambulatory, wheelchair subjects. Thus, only 8% of the total tasks attempted were unsuccessfully completed due to the inherent design of the device and/or the subject's inability to manipulate the device.

Table 10. Trial Performance as a Function of Reaching Height

Device	Successful Operation % n	Height of Device in mm (in.)
I. Architecture		
1. Telephone (AA4)		
a. Receiver (AA4a)	89.7	1415 (55.5)
b. Number Pad (AA4b)	79.5	1321 (52.0)
c. Coin Slot (AA4c)	77.5	1461 (57.5)
d. Coin Return (AA4e)	76.3	1060 (41.8)
2. Push bar door handle (AC1)	89.7	1041 (41.0)
3. Door Pull (AA19)	73.7	914 (36.0)
3. Elevator Call button (AB1)	97.5	1105 (43.5)
4. Elevator floor button (AB2)	94.8	1397 (55.0)
5. Water Fountain handle (AD22)	95.0	813 (32.0)
6. Rest Room Door Pull (AC19)	92.5	1181 (46.5)
7. Toilet Flush Valve (AD34)	72.5	1041 (41.0)
8. Faucet Handle (AD25)	85.0	940 (37.0)
II. Management		
1. Exterior Door Pull Handle (BA4)	69.8	1041 (41.0)
2. Water Fountain Handle (BA11)	95.2	940 (37.0)
3. Rest Room Door Pull (BA12)	92.9	1194 (47.0)
4. Toilet Flush Valve (BB24)	83.7	699 (27.5)
5. Faucet Handle (BA18)	87.8	965 (38.0)
6. Elevator Call Button (BA8)	95.0	1041 (41.0)
7. Elevator Floor Button (BB31)	95.0	1041 (41.0)
8. Push Bar Door Handle (BA6)	85.4	914 (36.0)
III. MARTA Station		
1. Elevator Call Button (DB16)	97.6	1067 (42.0)
2. Elevator Floor Button (DB13)	92.9	1168 (46.0)
3. Assistance Telephone (DC5)	92.9	1219 (48.0)
4. Fare card slot (DA7)	97.6	927 (36.5)
5. Coin Slot (DA6)	97.6	927 (36.5)
6. Fare Card Return (DA1)	95.0	978 (38.5)
7. Fare gate (DA16)	84.3	991 (39.0)
IV. Post Office		
1. Exterior Door Pull/Push (YA1)	66.7	1181 (46.5)
2. Stamp Machine (YA2)		
a. Coin Slot (YA2a)	56.1	1549 (61.0)
b. Selection Button (YA2b)	65.6	1499 (59.0)
c. Stamp Removal (YA2c)	53.3	1245 (49.0)
3. Mail Slot (YA3)	95.0	1194 (47.0)
4. P.O. Box (YA4)	77.0	1226 (48.3)
V. Shepherd Spinal Center		
1. Elevator call button (QB4)	97.5	1143 (45.0)
2. Elevator floor button (QB5)	95.1	1026 (40.4)
3. Door knob (QC3)	72.8	1054 (41.5)
4. Rest Room Door Pull (QC13)	90.2	1074 (42.3)
5. Toilet Flush Valve (QA1)	83.3	622 (24.5)
6. Faucet Handle (QA10)	95.2	978 (38.5)
7. Water Fountain Handle (QD1)	100.0	826 (32.5)
8. Door Handle (QC12)	97.6	1143 (40.5)
9. Door Push Bar Handle (QC5)	73.8	978 (38.5)

Posture. The most significant factor affecting performance appears to be associated with using a device while either standing or seated in a wheelchair. When the (1716 attempts are broken down into standing vs. sitting (see Table 11) 96.1% of those who were standing were able to successfully operate the devices whereas only 81.8% of those in wheelchairs were able to do so.

Moreover, whereas subjects who were standing were able to operate 36 of the 42 devices at least 90% of the time (it is interesting to note that 5 of the 6 devices which fell below 90% were located in the post office), only 12 devices could be considered as useable (above 90% success rate) by persons in wheelchairs (and 5 of those devices were elevator buttons).

Although height does not have a very high correlation with performance (r=-.30) and there are a number of devices at all heights which fall below the 90% success rate, it does, nonetheless, seem to play a significant role in affecting performance, particularly of those in wheelchairs. It is significant because as height increases, the inability to reach a device increases as a percentage of the number of unsuccessful attempts. As a result, devices which are able to be used when they are within reach (e.g. buttons) cannot be use when they are too high for wheelchair users.

Grip Type. Although subjects in the field testing used 9 of the 14 types of grips (see Tables 12 and 13), 6 of those, finger tip push, palmar push, hook grip, power grip, finger tip pinch and lateral finger pinch were clearly the dominant types, accounting for 93% of the primary grips and 96% of the secondary grips used for operating the devices. It also appears that devices are predominately used the way in which they were intended. That is, devices are primarily operated by only one or two grip types. As a result, the test devices can be categorized by grip type (see Table 14). For example, doors which pull open and telephone receivers are operated almost exclusively by hook or power grips; pinch-type grips are used to insert or remove things from slots and push-type grips are used for buttons and doors that push open. Although there are some exceptions where devices were operated by several types of grips, even the exceptions comprise fairly homogeneous groups of devices. These include: 1) wing faucet handles, 2) small lever handles on the telephone coin return and the water fountain in the Management Building and 3) toilet flush handles.

In general, most subjects were able to operate the devices using only a primary grip as there were a total of 1532 primary grips used while only 317 attempts required a secondary grip. However, secondary grips were frequently used on those devices which were the most difficult to operate and had the lowest rates of success. Specifically, the 10 (not including the two closet doors at Shepherd Spinal Center which did not have self-closing hinges) doors accounted for 61% (194 out of 317) of the total number of secondary grips used. Moreover, secondary grips were required to operate doors between 39% and 65% of the time, whereas only four other devices: coin return (39.5%), fare card slot (53.7%) and P.O. Box (30.7) and round door knob (21.4%) required a secondary grip more than 15% of the time (see Table 15).

The difficulty which subjects experienced with doors is also evident in the type of secondary grips which were used. Typically, a subject would either pull (using a hook or power grip) or push (using a palmar push) the door open and then use a secondary push grip to hold the door open while going through. This is reflected in the data which clearly show that the palmar push accounts for 44%

(140 out of 317) of the 9 secondary grip-types used. Moreover, 87% of the palmar push secondary grips were used to operate the 10 doors.

Table 11. Trial Performance as a Function of Posture

Device (in order of ascending height)	Successful Operation in % Standing	Successful Operation in % Seated
QA1	100.0	79.2
BB24	100.0	79.3
AD22	91.7	96.4
QD1	100.0	100.0
AA19, BA6	92.3	74.5
DA7, DA6	100.0	96.4
AD25, BA11	96.3	88.9
BA18	100.0	81.5
DA1, QA10,QC5	97.7	83.1
DA16	91.7	80.8
QB5	100.0	92.9
QC12	100.0	96.0
AC1, AD34, BA4, BA8, BB31,	100.0	76.5
QC3	93.3	61.5
AA4e	80.0	66.7
DB16	100.0	96.4
QC13	100.0	83.3
AB1	91.7	100.0
QB4	100.0	96.4
DB13	100.0	89.7
AC19, YA1,	89.3	73.1
BA12, YA3	100.0	90.6
DC5	100.0	93.1
YA4	83.3	73.1
YA2c	75.0	45.4
AA4b	92.3	70.4
AB2	100.0	92.6
AA4a	100.0	84.6
AA4c	92.3	73.1
YA2b	88.9	63.6
YA2c	88.9	27.3
TOTAL	96.1	81.8

Table 12. Types of Primary Grips Used to Operate Test Devices

Type of Primary Grips (in%)

	Finger push	Palmar/ other push	Hook	Disk	Finger pinch	Lat pinch	Digito palmar	Power	Other
I. Architecture									
1. Telephone (AA4)									
a. Receiver (AA4a)	0	0	5.6	0	0	0	2.8	80.6	0
b. Number Pad (AA4b)	89.2	3.6	0	0	3.6	0	0	0	3.6
c. Coil Slot (AA4c)	6.2	0	0	0	34.9	59.4	0	0	0
d. Coin Return (AA4e)	41.3	6.9	0	0	27.6	10.3	13.8	0	0
2. Push bar door handle (AC1)	11.1	77.7	3.7	7.4	0	0	0	0	0
3. Door Pull (AA19)	2.9	2.0	31.4	0	0	0	0	62.9	0
4. Elevator Call button (AB1)	92.1	2.8	0	0	0	0	0	0	0
5. Elevator floor button (AB2)	88.9	11.1	0	0	0	0	0	0	0
6. Water Fountain handle (A022)	18.0	56.4	7.7	0	0	15.4	0	2.6	0
7. Rest Room Door Pull (AC19)	0	0	51.2	0	2.4	0	0	46.3	0
8. Toilet Flush Value (A034)	3.4	24.1	50.6	3.4	0	0	0	6.9	3.4
9. Faucet Handle (A025)	0	18.4	39.5	0	2.6	31.6	3.0	5.3	2.6
II. Management									
1. Exterior Door Pull Handle (BA4)	2.6	0	33.3	0	0	0	0	64.1	0
2. Water Fountain Handle (BA11)	19.0	14.3	0.5	2.4	11.9	42.9	0	0	0
3. Rest Room Door Pull (BA12)	2.4	0	38.1	0	0	0	0	0	0
4. Toilet Flush Value (BB24)	8.3	16.7	58.3	0	0	5.3	0	8.3	2.7
5. Faucet Handle (BA18)	10.5	5.3	55.3	0	5.3	15.8	0	5.3	2.6
6. Elevator Call Button (BA8)	92.5	7.5	0	0	0	0	0	0	0
7. Elevator Floor Button (BB31)	92.6	7.3	0	0	0	0	0	0	0
8. Push Bar Door Handle (BA6)	4.0	96.0	0	0	0	0	0	0	0
III. MARTA Station									
1. Elevator Call Button (OB16)	85.7	14.3	0	0	0	0	0	0	0
2. Elevator Floor Button (OB13)	85.0	12.5	0	0	0	0	0	0	2.5
3. Assistance Telephone (OC5)	0	0	15.0	0	2.5	0	0	2.5	0
4. Fare card slot (OA7)	16.7	0	0	0	33.3	50.0	0	0	0
5. Coin Slot (OA6)	2.4	2.4	0	0	33.3	59.5	0	0	0
6. Fare Card Return (OA1)	0	0	0	0	47.4	52.6	0	0	0
7. Fare gate (OA16)	0	100.0	0	0	0	0	0	0	0
IV. Post Office									
1. Exterior Door Pull (YA1)	0	25.9	55.5	0	0	0	3.7	14.8	0
2. Stamp Machine (YA2)									
a. Coin Slot (YA2a)	12.0	0	8.0	0	44.0	32.0	0	0	4.0
b. Selection Button (YA2b)	84.9	3.0	0	0	9.1	0	0	0	3.0
c. Stamp Removal (YA2c)	0	0	0	0	38.5	61.5	0	0	0
3. Mail Slot (YA3)	0	0	0	0	41.0	59.0	0	0	0
4. P.O. Box (YA4)	2.5	0	0	0	7.5	85.0	0	5.0	0
V. Shepherd Spinal Center									
1. Elevator call button (QB4)	92.7	7.3	0	0	0	0	0	0	0
2. Elevator floor button (QB5)	99.5	11.5	0	0	0	0	0	0	0
3. Door knob (QC3)	0	2.4	0	78.5	0	0	2.4	14.3	2.4
4. Rest Room Door Pull (QC13)	0	2.6	0	43.6	0	0	0	53.8	0
5. Toilet Flush Value (QA1)	11.8	14.7	58.8	2.9	0	2.9	0	5.8	2.9

Table 13. Types of Secondary Grips Used

	Finger push	Palmar or other push	Hook	Disc	Span	Finger pinch	Lateral pinch	Digital palmar	Power	Other	Total
N	46	140	57	5	3	7	30	1	24	4	317
% Total	14.5%	44.2%	18.0%	1.6%	.9%	2.2%	9.5%	.3%	7.6%	1.3%	100%

Table 14. Primary Grip by Device
(% of total grip used on the device)

Grab Grips (Hook/Power)	Pinch Grips (Finger/Lateral)	Push Grips (Finger/Palmer)
I. Power Grip Handles	I. Dispensers	I. Electric Controls
1. Telephone Receivers	1. DA1 (100.0)	1. Elevator Button
AA4a (86.2)	2. YA2c (100.0)	AB1 (99.9)
DC5 (97.5)		AB2 (100.0)
		BA8 (100.0)
		QB5 (100.0)
2. Door Pull Handles	II. Receptacles	BB31 (100.0)
AA19 (94.3)	1. Coin Slots	DB16 (100.0)
AC19 (97.5)	AA4c (94.3)	DB13 (97.5)
BA4 (97.4)	DA6 (92.8)	QB4 (100.0)
BA12 (97.6)	YA2a (76.0)	
YA1 (70.3)*		
QC3 (92.8)	2. Other Slots	2. Other Buttons
QC13 (97.4)	DA7 (83.3)	AA4b (92.8)
QC12 (90.0)	YA3 (100.0)	YA2b (87.9)
	YA4 (92.5)	QC12 (100.0)
		II. Door Push Handles
		AC1 (88.9)
		BA6 (100.0)
		DA16 (100.0)

*Door also could be pushed in and 25.9% used palmar push.

Table 15. **Devices Requiring Secondary Grips**

	Number of Grips Used	% Total Grips	% Total N/Device
I. Architecture			
1. Telephone (AA4)			
a. Receiver (AA4a)	7	1.9	15.0
b. Number Pad (AA4b)	2	.6	7.7
c. Coin Slot (AA4c)	3	1.9	5.0
d. Coin Return (AA4e)	15	4.7	39.5
2. Push bar door handle (AC1)	17	5.4	43.6
3. Door Pull (AA19)	25	7.9	62.5
3. Elevator Call button (AB1)	2	.6	5.0
4. Elevator floor button (AB2)	0	0	0.0
5. Water Fountain handle (AD22)	13	.95	7.3
6. Rest Room Door Pull (AC19)	23	7.3	57.5
7. Toilet Flush Value (AD34)	2	.6	5.0
8. Faucet Handle (AD25)	24	1.3	10.0
II. Management			
1. Exterior Door Pull Handle (BA4)	28	8.8	65.1
2. Water Fountain Handle (BA11)	4	1.2	9.3
3. Rest Room Door Pull (BA12)	23	7.3	53.5
4. Toilet Flush Value (BB24)	3	1.0	57.0
5. Faucet Handle (BA18)	5	1.5	12.2
6. Elevator Call Button (BA8)	0	0	0
7. Elevator Floor Button (BB31)	0	0	0
8. Push Bar Door Handle (BA6)	16	5.1	39.0
III. MARTA Station			
1. Elevator Call Button (DB16)	0	0	0
2. Elevator Floor Button (DB13)	0	0	0
3. Assistance Telephone (DC5)	0	0	0
4. Fare card slot (DA7)	22	6.9	53.7
5. Coin Slot (DA6)	4	1.3	9.8
6. Fare Card Return (DA1)	0	0	0
7. Fare gate (DA16)	12	3.8	31.6
IV. Post Office			
1. Exterior Door Pull (YA1)	17	5.4	40.5
2. Stamp Machine (YA2)			
a. Coin Slot (YA2a)	0	0	2.4
b. Selection Button (YA2b)	0	0	0
c. Stamp Removal (YA2c)	2	.6	6.7
3. Mail Slot (YA3)	3	.9	10.0
4. P.O. Box (YA4)	12	3.8	30.7
V. Shepherd Spinal Center			
1. Elevator call button (QB4)	1	.3	2.4
2. Elevator floor button (QB5)	3	.9	7.3
3. Door knob (QC3)	9	2.8	21.4
4. Rest Room Door Pull (QC13)	16	5.0	39.0
5. Toilet Flush Value (QA1)	0	0	4.8
6. Faucet Handle (QA10)	9	2.8	2.1
7. Water Fountain Handle (QD1)	4	1.3	9.5
8. Door Handle (QC12)	5	1.6	12.2
9. Door Push Bar Handle (QC5)	17	5.4	40.5

Grip Shape. All four of the generic grip shapes (areas, plate, bar and spheroid) were represented by the devices tested, although only one device, a door knob (QC3), represented a spheroid shape. In general, shape does not appear to influence overall performance. As Table 16 indicates, when performance is examined as a function of shape for the 42 devices tested, one-half (21) fell above the 90% cut-off point for an acceptable rate of success and one-half (21) fell below that point. Moreover, each of the individual grip shapes (with the exception of spheroid of which there was only one) was also fairly evenly split between those that fell above 90% and those that fell below. Further, when correlated with performance none of the grip shape dimensions (major length, minor length or circumference) had a correlation which was significant.

Table 16. Trial Performance as a Function of Grip Shape

Rate of Success	Grip Shape: Bar	Plate	Area	Spheroid	Total
Over 90%	6	10	4	1	21
Under 90%	4	12	5	0	21
TOTAL	10	22	9	1	42

Subjects did not particularly find that one shape caused more discomfort than another. As Table 17 illustrates, most subjects had a minimal amount of discomfort in using all shapes. Although there was a higher degree of discomfort reported with the spheroid shape (42.2% reported moderate to extreme discomfort), because only one spheroid grip was tested, there is really too little data available for comparison.

Table 17. Discomfort as a Function of Grip Shape

Discomfort	Grip Shape: Bar	Plate	Area	Spheroid
Minimum	73.9%	77.5%	83.8%	57.9%
Moderate	16.0%	14.1%	12.0%	21.1%
Extreme	10.1%	8.5%	4.2%	21.1%

Body Location is the point from which a device is operated. It is measured by the distance in one foot increments from which a device is operated (operating distance) and by the angle the device (body position). Few of the devices had obstructions which would have prevented subjects from operating the device from a position that was a close as possible to the device. This is reflected in the data which show that 83.8% of the time devices were operated from within 305mm

(12in.) of the device. Further, less than 1% of the trials were attempted from more than 610mm (24in.) away and none from more than 914mm (36in.).

Table 18. Trial Performance as a Function of Body Location

	n attempts	n failure	% failure
0-305mm (12in.)	1382	179	13%
306-610mm (24in.)	257	32	12.5%
611-914mm (36in.)	10	2	20%
	1649		

In general, when obstructions are not a factor, neither operating distance nor body position relative to the device appeared to be a significant determinant of successful task performance. This is reflected in Table 18 which illustrates the fairly even distribution of task failures (as a percent of total attempts at a specified distance) among the three operating distances. Further, an examination of approach position, that is, the angle between the subject and the center of the device, reveals that 84.3% of the trials were attempted from directly in front of the device. Of that percentage, 80.2% were a forward approach within 305mm (12 in.). Interestingly, the only other position which occurred with any sizeable frequency was 45 degrees to the left or right of the device when subjects were within 610 mm (24 in.). This approach accounted for 11.2% of all the trials while no other position accounted for more than 3.5% of the attempts. Thus 91.4% of all trials were either attempted from 90 degree at 305mm (12 in.) or 45 degree at 610mm (24 in.).

Often, a forward approach puts wheelchair users at a disadvantage because they cannot reach the device. The data, however, show that even when alternative approaches were possible, subjects used a forward approach the majority of the time (19 devices were used from a forward approach more than 90% of the time and an additional 15 were used in this way more than 80% of the time). Further, 11 out of the 12 devices on which non-ambulatory subjects had a 90% or better success rate were primarily operated from a forward approach. Thus, it does not appear that the ability to use a the device was negatively impacted by body position.

Although body location does not appear to have a significant influence on performance when overall performance is considered, it may have an affect when there are obstructions as is the case with the three toilet flush handles where the toilets themselves can create an obstruction. It is interesting to note that (excluding the three devices on the MARTA fare rate which could not be approached from 90 degrees) subjects did not attempt to operate any of the other devices from more than 305mm (12 in.) away or at a position other than 90 degrees less than 70% of the time. However, for the three toilets, subjects' did not attempt to use the devices within the 305mm (12 in)/90 degree range more than 62.5% of the time on AD34, 45.5% of the time on BB24 and 45.2% of the time QA1. None of these devices had a success rate over 90%.

Exertion and Discomfort. The majority (67%) subjects reported no or only minimal exertion (Table 20) using the devices, whereas only 16% reported a large amount exertion. Similarly, 78% reported little or no discomfort, (Table 19) while only 8% reported extreme discomfort.

The data also indicate that those products which required the most effort (highest mean rating on a 0-10 scale) also caused the most discomfort (correlation =.67). Furthermore, both exertion and discomfort are highly correlated with performance (r=.57 and .41 respectively) which indicates that the products which subjects reported as being the most difficult and requiring the most effort were also the ones which had the lowest success rates. Moreover, this tends to validate the self-report data as there is a great degree of consistency between actual performance and the self report data.

Factors Affecting Performance.

The data collected in the field tests are significant in a number of ways. First, a comparison of performance by device type (e.g. slots, buttons, etc.) can provide information about the design of devices. Second, a comparison of performance on similar types of products (e.g. telephone, doors etc.) which have different designs can provide information about the utility of various designs for equipment. Finally, a comparism of subject performance by environmental factors (mounting height, light levels, etc.) can provide insight into making more informed decisions about the design of the context in which devices are located.

Comparison of Devices. As defined in the building survey, there are 6 categories of devices: electric controls, power grip handles, precision grip handles, receptacles, dispensers and assist devices. The following discussion will cover the devices included in the testing which fall into 4 of these categories. No devices in the other two categories were tested because there were no precision grip handles found at any of the test sites and there were not a sufficient number of ambulatory subjects to test handrails or other support devices.

1. Electric Controls include buttons on the phone (AA4b), elevator (AB1,AB2, BA8, BB31, DB13, QB4, QB5) water fountain (QD1) and stamp machine (YA2b).

In general, subjects had little difficulty operating buttons. Performance on all of the devices except the number pad on the pay phone (79.5%) and the stamp machine (65.6%) was well over 90%. Moreover, if inability to reach the device is considered, performance on the pay phone buttons might also have been 100% (8 out of 8 failed because they could not reach) and the stamp machine buttons might have been over 90% (9 out of 11 could not complete the task because they could not reach the buttons). In fact the button control on the water fountain at Shepherd Spinal Center was the only device in which task performance was 100% for both ambulatory and non-ambulatory subjects.

Thus, it appears that buttons themselves, when located where they can be reached, do not pose a great problem for persons with hand impairments. In fact, all of the subjects operated all of these devices their hands (except one subject who reached with his hand and used a stick to push some of the buttons) and primarily used a finger push or some other type of push (knuckle, back of hand etc.) depending on how large the button was.

Table 19. **Discomfort Ratings**

Device (PIN)	Almost None (% n)	Mild-Moderate (% n)	Extreme (n%)
I. Architecture			
1. Telephone (AA4)			
a. Receiver (AA4a)	74.3	17.1	5.7
b. Number Pad (AA4b)	54.3	40.0	5.7
c. Coin Slot (AA4c)	75.8	15.2	9.1
d. Coin Return (AA4e)	72.7	18.2	9.1
2. Push bar door handle (AC1)	72.2	19.4	8.3
3. Door Pull (AA19)	43.8	28.1	28.1
3. Elevator Call button (AB1)	91.7	5.6	2.7
4. Elevator floor button (AB2)	91.1	5.9	2.9
5. Water Fountain handle (AD22)	91.7	8.3	0.0
6. Rest Room Door Pull (AC19)	67.6	16.2	16.2
7. Toilet Flush Value (AD34)	85.7	8.6	5.7
8. Faucet Handle (AD25)	78.4	21.6	0.0
II. Management			
1. Exterior Door Pull Handle (BA4)	35.0	35.0	30.0
2. Water Fountain Handle (BA11)	89.2	8.1	2.7
3. Rest Room Door Pull (BA12)	72.5	20.0	7.5
4. Toilet Flush Value (BB24)	84.2	15.8	0.0
5. Faucet Handle (BA18)	89.5	7.9	2.6
6. Elevator Call Button (BA8)	92.1	7.9	0.0
7. Elevator Floor Button (BB31)	92.1	5.3	2.6
8. Push Bar Door Handle (BA6)	59.5	21.6	18.9
III. MARTA Station			
1. Elevator Call Button (DB16)	95.0	5.0	0.0
2. Elevator Floor Button (DB13)	77.5	22.5	0.0
3. Assistance Telephone (DC5)	90.2	9.8	0.0
4. Fare card slot (DA7)	82.9	14.6	2.4
5. Coin Slot (DA6)	85.4	9.8	4.9
6. Fare Card Return (DA1)	94.9	5.1	0.0
7. Fare gate (DA16)	70.0	17.5	12.5
IV. Post Office			
1. Exterior Door Pull (YA1)	52.6	18.9	29.7
2. Stamp Machine (YA2)			
a. Coin Slot (YA2a)	50.0	21.2	24.2
b. Selection Button (YA2b)	74.3	14.3	11.4
c. Stamp Removal (YA2c)	60.7	28.6	10.7
3. Mail Slot (YA3)	94.7	5.3	0.0
4. P.O. Box (YA4)	58.3	22.2	19.4
V. Shepherd Spinal Center			
1. Elevator call button (QB4)	94.7	5.3	0.0
2. Elevator floor button (QB5)	94.1	5.9	0.0
3. Door knob (QC3)	61.1	22.2	16.7
4. Rest Room Door Pull (QC13)	77.8	16.7	5.5
5. Toilet Flush Value (QA1)	85.7	14.3	0.0
6. Faucet Handle (QA10)	94.6	2.7	2.7
7. Water Fountain Handle (QD1)	94.6	0.0	5.4
8. Door Handle (QC12)	92.1	7.9	0.0
9. Door Push Bar Handle (QC5)	57.9	21.1	21.1

Table 20. Product Exertion Ratings

Device	Force Required	N*	Min Rating	Max Rating	Mean Rating	S. Dev.	Frequency (in % of Total n) Minimal 0-2	Mild 3-6	Maximal 7-10
AA4a	3.0	37	0	10	3.0	3.49	63.9	22.2	13.9
AA4c	1.0	38	0	10	4.3	4.04	44.7	18.4	35.8
AA4b	N.A.	35	0	10	3.1	3.78	71.4	5.7	22.9
AA4C	N.A.	34	0	10	3.8	4.61	58.8	14.7	26.5
AC1	16.0	38	0	10	3.4	3.83	55.3	21.1	23.7
AA19	16.0	36	0	10	5.8	3.80	33.3	25.0	41.8
AB1	1.0	39	0	10	1.1	2.30	87.2	7.7	5.1
AB2	0.5	37	0	10	1.5	2.77	81.1	10.8	8.1
AD22	6.0	39	0	10	1.9	2.64	76.9	15.4	7.7
AC19	8.0	41	0	10	4.2	3.58	43.0	34.2	21.9
AD34	6.0	37	0	10	3.2	4.15	67.5	8.1	24.4
AD25	2.0	40	0	10	1.6	2.46	77.5	17.5	5.0
BA4	16.0	41	0	10	5.9	3.51	22.0	31.7	44.2
8A11	6.0	40	0	10	2.2	2.91	70.0	22.5	7.5
BA12	8.0	42	0	10	3.1	3.25	64.2	21.4	14.3
B824	6.0	40	0	10	2.1	2.90	72.5	17.5	10.0
8A18	6.0	41	0	10	1.9	3.00	83.0	7.3	9.7
8A8	1.0	41	0	5	0.7	1.60	87.7	12.2	0.0
BB31	1.0	41	0	5	0.8	1.54	87.7	12.2	0.0
8A6	16.0	40	0	10	4.5	3.61	32.5	40.0	27.5
DB16	1.0	42	0	7	0.5	1.20	97.6	0.0	2.5
D813	2.0	41	0	10	1.8	2.56	70.7	22.0	7.3
DC5	3.0	42	0	7	1.2	1.85	78.6	19.0	2.4
DA7	N.A.	42	0	9	1.7	2.51	80.9	11.9	7.2
DA6	N.A.	42	0	9	1.7	2.54	80.9	11.9	7.2
DA1	N.A.	40	0	10	1.2	2.17	85.0	12.5	2.5
DA16	6.0	40	0	10	3.6	3.58	50.0	30.0	20.0
YA1	12.0	42	0	10	4.7	4.22	42.8	19.1	38.1
YA2A	N.A	40	0	10	4.5	4.33	45.0	12.5	42.5
YA2B	1.0	40	0	10	2.3	3.45	70.0	12.5	17.5
YA2C	N.A.	28	0	10	4.0	3.67	39.3	35.7	25.0
YA3	N.A.	41	0	10	1.1	2.06	92.7	2.4	4.8
YA4	N.A.	39	0	10	4.6	3.66	33.3	41.0	26.6
QB4	1.0	41	0	10	1.2	2.20	80.5	17.0	2.5
QB5	1.0	39	0	10	1.5	2.69	84.6	10.3	5.1
QC3**	4.0/6.0	40	0	10	5.2	4.15	35.0	25.0	40.0
QC13	6.0	40	0	10	2.25	2.88	65.0	25.0	10.0
QA1	4.0	38	0	10	2.4	3.39	73.7	10.5	15.8
QA10	2.0	41	0	10	1.4	2.15	85.4	12.2	2.2
QD1	3.0	40	0	6	0.9	1.69	82.5	15.0	2.5
QC12**	3.0/6.0	40	0	10	1.3	2.39	87.5	7.5	5.0
QC5	14.0	40	0	10	4.3	4.13	50.0	20.0	30.0

* The variation in N is a result of subjects who did not use a device either because they were unable to reach the device or did not complete the testing.

** The first value indicates the force required to operate the handle, the second is the force to pull the door.

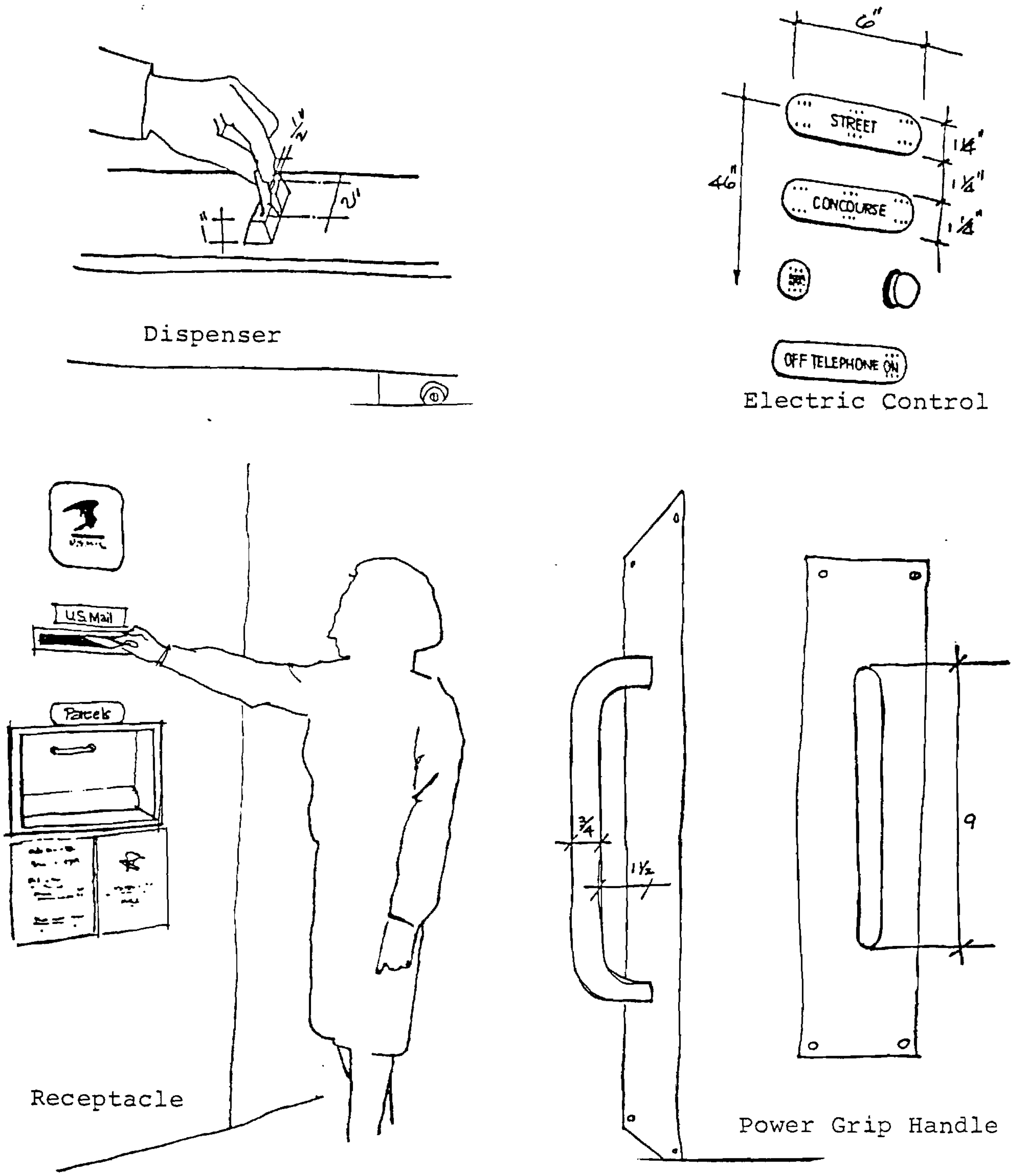


Figure 5. Examples of the Device Categories

2. Power Grip Handles is a category which represents a range of different devices including: toilet flush handles (AD34, BB24, QA1), water fountain handles (AD22, BA18), door handles (AC1, AA19, BA4, BA6, BA12, DA16, YA1, QC13, QC5, QC3, QC12), telephone receivers (AA4a, DC5) and sink faucet handles (AD25, BA18, QA10).

Because of the diversity of grip shapes, uses, possible grips and locations of the devices, this category is perhaps the most difficult to evaluate. Perhaps the only clear indication from the performance data which ranges from a low of 69.8% success rate (BA4-entry door) to a high of 97.69% (QC12-lever handle), is that the problems in use are less a function of a type of potential grip than they are of other contextual factors such as the inability to reach (e.g. getting close enough to a toilet flush handle from a wheelchair), the amount of force required (e.g. to open a door), or the type of motion required to use a device (e.g. lifting a telephone receiver off the hook).

In addition, people tended to use not only multiple grips to operate these devices but they also tended to use other parts of their bodies (e.g. hips, legs, fore-arms) as well as wheelchairs, to operate these devices either in whole or in part. For example, only 47% the subjects who successfully went through the MARTA fare gate used just their hands; 12% used other parts of their body to aid in getting through; and 41% used their wheelchair to push the gate open.

However, those devices which were operated primarily by the hand alone tend to reflect a higher rate of successful performance than those which required subjects to use alternate methods for either partial or complete operation,. For example, faucet and water fountain handles were operated almost exclusively by hand (92% or more of the time) and had success rates ranging from 85-95%. On the other hand, entry/exit doors required much greater force to operate and subjects therefore used other parts of their anatomy to aid in the operation of these products. In fact, the 7 entry doors accounted for 58% of all of the times that subjects used some other means to aid in performing a task. Coincidentally, none of the doors had an acceptable rate of success (over 90%) and they were, as a group, typically lower (ranging from only 66% to 89.7%) than the other groups of devices.

Receptacles include coin slots (AA4c, DA6, YA2a), card slots (DA7), key slots (YA4) and mail slots (YA3). Within this group there was a great disparity in the success rates on the five slots tested, ranging from a low of 53.7% (which was the second lowest rate for all devices) to a high of 97.6%. Again, however, the range is misleading. The two worst slots, the coin slots on the telephone (AA4c) and stamp machine (YA2a) were also the two highest from the floor, 1461mm (57.5 in.) and 1549mm (61 in.), respectively. As a consequence, of those subjects who failed to use those two devices 8 out of 9 subjects (phone) and 19 of 19 subjects (stamp machine) could not reach the slots to insert the coin. This tended to have the greatest impact on the non-ambulatory subjects as only 73% could use the phone and 27% on the stamp machine. Moreover, these slots were also the smallest of the group, thereby requiring the most precision. In contrast, the coin slot on the MARTA fare machine was located on a flat surface (horizontal to the ground) and was dished so as to catch the coins deposited as opposed to the vertical coin slots on the phone and stamp machine. Being only 927mm (36.5in.) from the ground allowed subjects (particularly those in wheelchairs) to place the coin on the fare machine and slide it into the enlarged slot. The result was a 97.6% success rate (one non-ambulatory person could not operate the device).

Interestingly, the card slot on the fare machine which worked by a similar principal of sliding the card along a horizontal surface until it was just in the machine (at which point the machine would eat the card and pass it out the top) had the same 97.6% success rate as the coin slot.

The mail slot, which in comparison to the other slots was far larger than the object to be inserted in it, had a very high success rate (almost 95%) as well. Because the slot presented a large target, many people simply flicked the envelope into the slot without having to reach to the 1194mm (47 in.) height at which the slot was located. As a result, only two (2) wheelchair-bound subjects were unable to complete the task.

Finally, the key slot proved to be troublesome for both the standing (83.3% success) and seated (73.1%) groups. However, this was not necessarily related to an inability to put the key in the slot. Rather, it was the inability to work the lock mechanism.. Either the key was difficult to turn or subjects turned and waited for the lock to click open. Because subjects were unfamiliar with the device, they did not know that they had to turn and pull at the same time. As a consequence subjects often kept turning the key without being able to open the door.

4. Dispensers include the coin return (AA4e) on the telephone, the fare card return DA1) and the stamp removal (YA2c) from the stamp machine. Like the slots, these devices are so diverse in nature that the rate of successful performance ranged from the 53.3% (which was the lowest of 42 devices) for the stamp machine, to 76.3% for the coin return and 95.0% for the fare card return.

Comparing the stamp and the fare card makes some sense not only because both are ejected from the machine and must be grabbed to be removed but also because both required a pinch-type grip to be used (97% used a pinch-type on the fare card, 96% on the stamp). The fare card, which is the size of a credit card, stuck almost completely out of the machine and therefore had a fairly large surface (about 76mm or 3in.) to grab. The stamp on the other hand, barely (about 13mm or 1/2in.) protruded from the machine, and at best, even non-hand impaired users had a hard time trying to get the stamp out without ripping it.

The coin return seems to be a different type of dispenser in that it required several different steps and grips (e.g. insert finger, locate coin, trap coin, slide it out and pinch it) to secure the coin.

Product Comparison. There are several pieces of equipment which were tested at a number of sites and which either fall into different device categories (e.g. a water fountain button and a water fountain handle) or are subcategories of a larger device group (e.g. elevator call buttons). These products include: elevator buttons, interior entry/exit doors, exterior entry/exit doors, interior doors, water fountains, toilets and sinks faucets.

1. Elevator Buttons include both call buttons (AB1, BA8, DB16, QB4) and floor buttons (AB2, BB31, DB13, QB5). In all instances, task performance on the call buttons was equal to or greater than the performance on the floor buttons of the same elevator. However, the differences in success rates were not only insignificant, but the overall rates (93-98%) for elevator buttons were the highest of any of the products tested in the field. When performance is examined

as a function of posture, the data reveal that none of the ambulatory subjects failed to operate the devices and whereas only non-ambulatory subjects failed to successfully operate the buttons, no more than three subjects failed to operate any one button.

There were, however, differences among the buttons which are not reflected in the performance data. First, although the success rate on the MARTA elevator was high (97.6% for the call button and 92.9% for the floor button) for the general sample, DB13 was just under 90% for the non-ambulatory group. There were a number of problems arising from both the design and the signing of the floor buttons. Not only is the oblong shape of the buttons unusual, but they are also labelled abstractly with the terms "street" and "concourse". As a result, when subjects were told to take the elevator down, they either pushed the "familiar" round button on the botton which was actually the "door open" button, or they asked which button went down to the station. Therefore, when told which button to push, 92.9% of the subjects were able to accomplish the task.

Another problem arose with the call button at Shepherd Spinal Center. Although subjects had no trouble activating the pressure sensitive button (97.5% success rate), they did experience problems similar to those observed in the naturalistic studies. Specifically, because the button did not light to indicate that it had been activated, subjects often hit the button repeatedly until the elevator door opened, reassuring them that they had indeed operated the button.

Finally, many subjects remarked that the button on the elevator at the Architecture Building (which was unfortunately replaced midway through the testing) was the easiest to use even though it actually took more force to operate than some of the others. Unlike the recessed, pressure or heat sensitive buttons, which only provided a small surface area which could be activated with one's finger, this button protruded 3mm (1/8 in.) from the wall which enabled subjects to use almost any part of their hand or body to activate the button. This difference is perhaps the reason why AB1 was the only button which had a 100% success rate among the wheelchair subjects. When the same button, however, was raised from 1405mm (43.5 in) to 1397mm (55 in.) as was the case with AB2, success dropped from 100 to 92.5%. Although this is still an acceptable rate, had it been one of the other button types, it might not have been.

2. Inside entry/exit doors (AC1, BA6, QC5) are those doors which push open. One factor which is common to all of these products is that they require more force than any of the other devices. Whereas all of the other non-entry doors range from 0 to 3.5 kg (8 pounds) of force, the three entry doors required 5.4-7.3 kg (12-16 pounds) to be operated. Even the (so-called) power assist doors at the Management Building required 7.3 kg (16 pounds) of force to open.

Because such a large amount of effort was required to operate these products, this was corroborated by the self report exertion date and because the doors were, in some cases, able to be opened without pushing a handle to unlatch a lock, a large proportion of the test subjects utilized both of their hands and/or alternate methods to open these doors. Even so, the performance ratings were unacceptable only ranging from 74.4-89.7%.

3. Exterior entry doors (AA19, BA4, YA1) have, as a group, the worse success rates of any of the products tested. Both the Architecture and Management entry doors required 7.3 kg (16 pounds) of force, while the post office took 5.4 kg (12

pounds) to pull open. Then the subjects had to get around the open door and through the doorway before the door swung shut. This was particularly difficult for a wheelchair user to do. As a consequence, the success rates were only 74% (Architecture), 70% (Management), and 67% (Post Office).

Although the post office door took less force to operate than the other two, its lower rate of success is probably due to the very slight incline up to the entry. This prevented wheelchair users from rolling from a stationary position because they had to hold the door open with one hand while trying to move the chair with the other.

4. Interior doors (AC19, QC3, QC13, BA12, QC12), like exterior entry doors also pull open, but unlike the latter group, are much lighter in weight and none required more than 3.6 kg (8 pounds) of force to open. As a consequence, the performance rates are far higher on these doors than on the entry doors. In fact, with the exception of QC3, the success rates ranged from 90%-97.6%.

QC3 is one of the few products where the inability to perform a task can be directly linked to a hand related problem. Although this particular door was identical to the two other interior doors at Shepherd Spinal Center (QC13, QC12), its handle was very different. Whereas one of the latter two had a pull handle and the other had a lever handle, QC3 had a round door knob. Moreover, every other door tested in this group had pull handles. Unlike the handles which could be operated by any number of variations on the power or hook grip, the knob could only be operated by a disc grip. As result, only 73% of the subjects were able to open the door.

5. Water fountains (AD22, BA11, QD1) are an interesting category because although each of the three products had a different type of operating mechanism, the success rates were very high and only varied slightly (from 95% to 100%). However, despite the apparent ease in operating the control, very few of the non-ambulatory subjects could actually drink from the fountain. This was a result of their inability either to reach the stream of water or to prevent water from spilling all over them. Therefore, despite the appropriateness of the hand controlled mechanisms, the overall design of the fountain and its location should to be re-evalauted.

6. Toilets (AD34, QA1, BB24) appear to create problems that are related to both the design of the product as well as the design of the environment in which they are located. There were marked differences in the design of the three "accessible stalls" which can account for the differences in the success rates of AD34 (rate = 72.5%) and the other two which had similar identical rates of 83.3% and 83.7% respectively). First the mounting height of the handles varied from 622mm (24.5 inches)and 699mm (27.5 inches) for QA1 and BB24, respectively, to 1041mm (41 inches) for AD34. Second, the stall in the Architecture Building (AD34) was only 914mm (3 feet) wide, whereas the other two were 1524mm (5 feet) in width.

These factors are extremely important because although none of the ambulatory subjects failed to operate the device, wheelchair-bound subjects failed 25 times. In addition, 22 out of the 25 failures on the 3 toilets were the result of wheelchair subjects not being able to reach the handle. Moreover, half of those failures occurred in the Architecture Building (AD34) alone, where wheelchair users were forced to reach across the toilet from the front in order to operate the handle. At the other two sites subjects could pull alongside the flush handle and simply reach over to use it. However, because these two handles were so low, the failures in these cases resulted from subjects who could not lean over to operate the handle without falling out of their chairs.

7. Sink faucets (AD25, QA10, BA18) were all of a similar wing, lever-type design located on sinks that were open underneath to allow wheelchair access. The differences among the faucets seem to be related to the amount of force required to operate the mechanism. The faucet at Shepherd (QA10) had a 95.2% success rate and only required 0.9 kg (2 pounds) of force to operate. In contrast, BA18 had only an 87.8% success rate and required 2.7 kg (6 pounds) of force to operate. Finally, AD34 required anywhere from 0.9 to 2.7 kg (2.5 to 6 pounds) of force depending on how far the handles were pushed in the off position by the previous user. As a result, despite the 85% success rate, two users could not turn the water on at all because the handle had been turned too far off. Had these two subjects been able to operate the device, the success rate would have been 90%.

Comparison of Contextual and Product-Related Factors. Although environmental measures (light and noise levels, temperature, etc.) were gathered at the test sites, there was little, if any variation in these factors during the course of the project. As a consequence, these conditions probably had little influence on the subjects' ability to perform the tasks. The results of this study do suggest however, that the major determinants of successful operation of hand oriented devices are: 1) operating distance (including reach) and 2) force required to operate the device. Both appear to have a large impact on non-ambulatory individuals.

First, task performance appears to be impacted by the distance that a person is situated from the device. This is primarily a problem for wheelchair users who are affected by obstructions and the height above the floor at which the device is mounted. This was evident in the bathroom stalls, particularly in the Architecture Building (AD34) where the 914mm (3-foot) wide stall prevented wheelchair-bound subjects from pulling alongside the flush handle in order to operate it. Forced to reach across the entire length of the toilet, all 11 subjects who failed to flush (AD34) did so because they could not reach the handle.

An even more significant factor affecting task performance in this particular study appears to be the large variation in mounting heights which ranged from 622 to 1549mm (24.5 to 61in.) from the floor. Within this range of heights tested, subjects in wheelchairs had the most difficulty reaching heights over 1321mm (52 in.) and under 825mm (24.5 in.). The high devices included the public telephone receiver 1415mm (55.5 in.), coin slots at 1461mm (57.5 and 1549mm (61 in.), upper floor elevator buttons 1397mm (55 in.), telephone buttons 1321mm (52.0 in.) and stamp machine buttons 1499mm (59 in.). The low mounted devices were the two toilet flush handles which were 622mm (24.5in.) and 699mm (27.5in.) from the floor.

Whereas height is not highly correlated with performance, devices (e.g. the elevator buttons in the Architecture Building) which are easily used at lower heights become more difficult to use at higher heights. The performance data indicate that the 46 out of 53 subjects who failed to operate those devices over

1321mm (52 in.) in height, failed to do so because they could not reach the device. Similarly, 14 out of 17 subjects who failed to operate the two low flush handles also failed because they could not reach the device. In contrast, for all of the other devices tested which ranged from 826mm (32.5in.) to 1245mm (49in.) in height only 2 out of 169 failures were attributable to the subject's inability to reach the device. Thus, it appears that those devices which are unobstructed and which are mounted within a range of 826 to 1245mm (32.5 to 49in.) from the floor (to the midpoint of the device) at least provide the opportunity to be operated. Those that fall outside this range are either too high or too low and are apt not to be reached by wheelchair users. As a consequence, the design of the device would make little difference.

The second key influence is the amount of force required to operate a device. This is particularly relevent to devices which required grab-type grips, such as power or hook grips. These devices required, on the average, more power (mean force of 3.8 kg or 8.3 pounds) to operate than any of the other categories and accounted for 38% (63) of the 167 failures not attributable to reach. As a result there is a high negative correlation (r=-.50) between performance and force required. This indicates that the greater the amount of force required to operate a device the lower the rate of successful performance there will be.

Specifically, the data indicate that those devices tested in this study that required more than 5.4 kg (12 pounds) of pushing or pulling force (all are entry/exit doors) cause the most difficulty in task performance. Although the six doors which fall into this category have performance rates from a low of 66.7% to a high of 89%, 4 out of 6 have rates of less than 74%; and while there are other factors which can account for differences within this group (push versus pull open, inclined approach to the doorway, etc,) the most significant factor in ability to use doors appears to be the amount of force required to open the door wide enough to get through. As soon as the force drops down to 3.6 kg (8 pounds), which is the case with the interior doors, the success rate jumps to over 90%.

Whereas both operating distance and force individually affect performance, it appears that the two factors acting together may also account for the low success rates of the wheelchair subjects. Even though most of the devices were within the acceptable ranges of height and force, wheelchair subjects, nonetheless, were only able to operate 10 devices at a minimum acceptable success rate of 90%. This can be explained, in part, by the fact that wheelchair-bound persons are forced to grip and operate devices (which were designed to be used while standing) from a sitting position. The combination of reach and force can cause problems with leverage thus explaining why wheelchair users have difficulty with some devices which require less than 5.4 kg (12 pounds) of force and are located lower than 1321mm (52in.) or higher than 699mm (27.5 in.). This may explain, for example, why the two faucet handles which required 2.7 kg (6 pounds) of force had success rates less than 90% whereas the handle which required only .9 kg (2 pounds) had a success rate over 95%.

CONCLUSIONS

In sum, there a number of factors which affect the use of devices. These include factors which are related to the design of the device, the design of the equipment on which the device is located and the design of the environment in which the equipment is found. While laboratory research is good at determining which factors relating to the design of devices are most important, field research is more appropriate for examining the latter two areas of contextual issues. As a consequence, it is not surprising that the major findings of the field testing relate to the context rather than to the design of the devices themselves.

Specifically, the data indicate that regardless of an individual's hand impairment, posture (whether somone is in a wheelchair or standing), is the most important factor in task performance. Ninety-six percent of the time subjects who were standing were able to successfully perform the task. Subjects in wheelchairs were successful only 82% of the time. Moreover, the two key influences on posture appear to be operating distance and force. Whereas persons with hand impairments generally have little difficulty using buttons, they also have little difficulty with levers, pulls and even slots, when the devices are located between 825 and 1214mm (32.5 and 48 inches) from the floor and when the equipment does not require more than 5.4 kg (12 pounds) of force to operate. In addition, the ground should be level at the operating position (especially at doorways) in order for non-ambulatory people to effectively use the environment.

Nonetheless, despite the abundance of data on contextual problems there are some conclusions to be drawn about the devices themselves. First, although performance rates on certain slots were low because subjects could not reach them, many subjects who were able to insert the coins (or key) had a great deal of difficulty in doing so. Slots could be much easier to use if they required less precision. The MARTA fare machine, in addition to having the coin and card slots lower to the ground than the other slots tested, also required less precision by locating the devices on horizontal surfaces which act as "catchers" for the coins or the card, thereby requiring less precision on the part of the user. Despite the need for directions on how to use the fare machine, these innovations seem to work extremely well.

Second, most people seem to be able to make some semblance of a hook/power grip; and despite problems inherent in the design of the equipment (e.g. the weight of the door) which made doors difficult to use, few subjects had trouble grabbing door pulls or most of the other handles with which these grips can be used. However, the round door knob, which was placed on a door identical to two others, one with a pull and the other with a lever handle had a far lower rate of success in task performance (72.8% versus 90.2% and 97.6% respectively) than the other two. The significant difference seems to be totally attributable to the spherical knob.

Third, dispensers are effective only when the object they dispense protrudes far enough to be grabbed. While there is not enough data to make a recommendation on this issue, the 13mm (1/2 inch) that a postage stamp protrudes from a stamp machine is clearly not far enough. However, the 76mm (3 inches) that the Fare Card protrudes may be more than is necessary. While other data are needed to the optimum dispensation, it is apparent that the longer the object protrudes, the greater amount of flexibility which an individual has in being able to grab it in a way which will be suitable to him/her.

Finally, the amount a device protrudes from the mounting surface also plays a role in ease of operation. Although the elevator button in the Architecture Building did not have a higher success rate than some of the other elevator buttons, subjects reported that they felt that it was easier to use (despite the fact that it required twice the force of some of the other buttons) because it stuck out and was therefore easier to hit with any part of one's hand (or other body part if one so desired).

From this study it appears that devices which are most effective are those which are the most flexible and most forgiving. That is, they are devices which offer the opportunity for an individual to use them in any number of different ways. This is evident in many of the devices studied. For example, dispensers like the fare card machine which dispense objects which protrude a large amount provide the opportunity for a person to use a whatever grip he/she can (one person even used his mouth). Similarly, coin slots like the one on the fare machine which has a dish to catch coins eliminates the need for the precision demanded by a narrow vertical slot. Elevator buttons that protrude and are spring-operated so they can be activated by almost anything that can produce 0.9 kg (2 pounds) of pushing force are also effective. Finally, there are a number of door handles which can be gripped and pulled using an infinite number of variations on the power/hook grip. All of these options maximize flexibility and forgiveness in the devices and eliminate the need for precision, strength and a singular grip, thereby making the devices easier to operate by individuals with hand impairments. Unfortunately, none of these will be effective if people in wheelchairs cannot reach them.